THE TEXTILE FIBRES

THEIR PHYSICAL, MICROSCOPICAL

AND

CHEMICAL PROPERTIES

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PREFACE.

THE present book, it is hoped, will be of assistance to both
the practical operator in textiles and the student on textile
subjects. It has been the outgrowth of a number of years of
experience in the teaching of textile chemistry, as well as prac-
tical observation in the many mill problems which have come
under the notice of the author.

The textile fibres form the raw materials for many of our
greatest industries, and hence it is of importance that the facts
concerning them should be systematized into some form of
scientific knowledge. The author has attempted, however, not
to allow the purely scientific phase of the subject to overbalance
the practical bearing of such knowledge on the every-day problems
of industry.

Heretofore, the literature on the textile fibres has been chiefly
confined to a chapter or two in general treatises on dyeing or
other textile subjects, or to specialized books such as Höhnel's
work on the microscopy of the fibres. It has been the author's
endeavor, in the present volume, to bring together, as far as
possible, all of the material available for the study of the textile
fibres. Such material is as yet incomplete and rather poorly
organized at its best; but it is hoped that this volume may prove
a stimulus along the several lines of research which are available
in this field. Unfortunately, the subject of the textile fibres
has been lamentably neglected by chemists, although there is
abundant indication that a fertile field of research is open to
chemists in this direction, and such work would have not only

a scientific value, but might also lead to great industrial worth. There is, as yet, relatively little known concerning the chemical constituents of the fibres, and the manner in which varying chemical conditions affect the composition and properties of these constituents. The action of various chemical agents on the fibre as an individual has been but very imperfectly studied. More work has been done in the microscopical field concerning the properties of the fibres; but even here the knowledge is very incomplete and disjointed, and especial attention is drawn to the fact there is yet a large amount of work to be done in the microchemistry of the subject.

The author has endeavored to emphasize throughout this volume the importance of the study of the fibre as an individual, for in many cases it is misleading to assume that the behavior of the individual fibre is identical with that of a large mass of fibres in the form of yarn or cloth. In the latter case, the difference in physical condition and the action of mechanical forces has an important influence. By going back to the study of the individual fibre as a basis, many explanations can be given which could not be discovered otherwise.

It is hoped that this book may afford instruction both to the manufacturer and to the student; assisting the former in solving some of the many practical problems constantly occurring in the manufacture of textiles, and urging the latter on to an increased effort in the scientific development of the subject.

<div align="right">J. MERRITT MATTHEWS.</div>

PHILADELPHIA TEXTILE SCHOOL,
    January, 1907.

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THE TEXTILE FIBRES.

CHAPTER I.

CLASSIFICATION OF THE TEXTILE FIBRES.

1. Fibres Chiefly Used for Textiles.—In order to be service-able in a textile fabric, a fibre must possess sufficient length to be woven and a physical structure which will permit of several fibres being spun together, thereby yielding a continuous thread of considerable tensile strength and pliability. Although there are several fibres, such as spun glass, asbestos, various grasses, etc., which are used for the manufacture of textiles in peculiar and rare instances, yet the fibres which are employed to the greatest extent and which exhibit the most satisfactory qualities are wool, silk, cotton, and linen. All of these possess an organ-ized structure, and are the products of a natural growth in life processes.

According to Georgevics, all textile fibres may be divided into four distinct classes; and though the same general arrange-ment is here preserved, the order has been somewhat changed so as to bring the most prominent ones first: (1) *Animal fibres;* (2) *Vegetable fibres;* (3) *Mineral fibres;* (4) *Artificial fibres.*

2. Animal and Vegetable Fibres.—According to their origin, we may divide the principal fibres into two general classes, those derived from animal and those derived from vegetable life. The former includes **wool** and **silk,** and the latter **cotton** and **linen.** **Animal fibres** are essentially nitrogenous substances (protein

matter),* and in some cases contain sulphur. They may also be solid filaments formed from a liquid secretion of certain cater-pillars, spiders, or molluscs. Alkalies readily attack the animal fibres, causing them to be dissolved, but they withstand the action of mineral acids to a considerable degree. Contrary to the
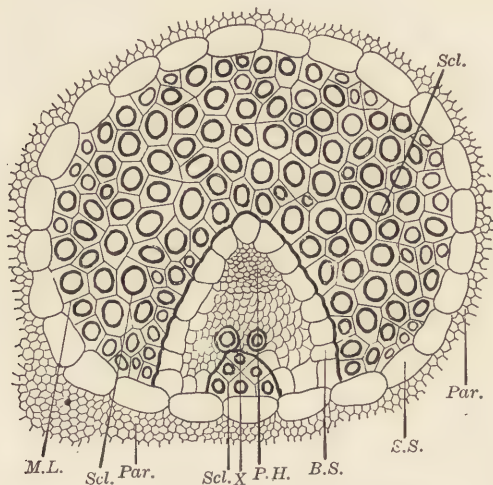
FIG. 1.—Section of Vascular Bundle of Sisal Hemp.   (×300.)

Par, cellular parenchyma; *S.S.*, starch layer; *Scl*, sclerenchyma; *M.L.*, middle lamella; *B.S.*, bundle sheath; *X*, xylem or wood cells; *P.H.*, phloëm or bast cells.   (After Morris.)

vegetable fibres, they are readily injured if exposed to elevated temperatures. **Vegetable fibres** consist of plant-cells,† usually

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* Protein matter is of the character of albumin, and forms one of the prin-cipal ingredients of animal tissues. It is essentially nitrogenous in composition and is especially characterized by the peculiar empyreumatic odor evolved when burned. One of the readiest and most conclusive tests, in fact, which may be used to distinguish between an animal and a vegetable fibre is to notice the odor evolved on burning in the air. With regard to their physical condition, it may be said the proteids composing the animal fibres are essentially of a *colloidal* nature; that is, they resemble a solidified jelly in condition. This property of the fibres may be used, to a great extent, to explain their action with solutions of dyestuffs and metallic salts, in which the theory of solid solution and osmosis comes into play.

† Plant-cells are of different character and size depending on the part of the

rather simple in structure and forming an integral part of the plant itself. They are capable of withstanding rather high temperatures, and are not weakened or disinte-grated by the action of dilute alkalies. They consist essentially of cellulose, which may be in a very pure form or be mixed with its various alteration products. In some cases the fibre consists of some cellulose derivative obtained by chemical means, such, for instance, as mercerized cotton. Concentrated alkalies produce alteration products with the vegetable fibres. Free sul-phuric or hydrochloric acid, even if only mod-erately strong, will quickly attack the fibre, disintegrating its organic structure and forming hydrolyzed products. Nitric acid, on the other hand, forms nitrated celluloses (the so-called nitro-celluloses) and various oxidation derivatives.

FIG. 2.
Cells of Wood
Tissue. ($\times$500.)
(After Gray.)

It is generally considered that the animal fibres have a lower conductivity for heat than have the vegetable fibres, and in consequence fabrics made from wool and silk are warmer than those made from cotton and linen.*

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plant in which they occur and the office or function they perform in the develop-ment of the plant tissue. These cells consist of tubes generally between 0.001 in. and 0.002 in. in diameter; their ends are usually pointed and in their arrange-ment overlap one another. (See Fig. 2.) In the fibrous layers occurring in plants these cells are sufficiently long and so interlaced as to give a fibre of considerable strength, whereas in plain woody tissue the cells are short and properly speak-ing yield no fibre of sufficient strength or length to be used for textile purposes. In monocotyledons, according to Dr. Morris, the fibrous cells are found built up with vessels into a composite structure known as fibro-vascular bundles; these bundles occur in the leaves and stems, but not in the outer bark of plants (see Fig. 1), and are usually found imbedded in a soft cellular tissue known as *parenchyma.*

* Count Rumford made some interesting experiments relative to the "heat-retaining value" of various clothing materials. He heated a large thermometer to a given temperature and then ascertained the length of time required for the thermometer to fall to a given point when surrounded with the various mate-rials experimented upon. The times taken by the thermometer in falling from

3. Mineral and Artificial Fibres.—These two classes of fibres are of rare occurrence in the textile industry when compared with the extensive use of the preceding fibres. They find a limited use, however, for certain purposes, and deserve to be considered in a systematic study of the subject. The principal, and strictly speaking the only, mineral fibre is **asbestos**, which occurs in nature as the mineral of that name. It is a fibrous silicate of magnesium and calcium, though often containing iron and aluminium in its composition, especially in the dark-colored varieties.* This mineral, though in the form of a hard rock, can be easily separated into slender † white fibres (Fig. 3), sometimes inclining

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70° to 10° Réaumur, when surrounded with various substances, were as follows:

	Seconds.
Air.	576
Raw silk.	1284
Sheep's wool.	118
Cotton.	1046
Fine lint.	1032
Beaver's fur.	1296
Hare's fur.	1315
Eiderdown.	1305

In another series of experiments, however, using the same materials differently arranged, very different results were obtained:

	Seconds.
Sheep's wool, loosely arranged.	1118
Woolen thread, wound round bulb.	934
Cotton, loose.	1046
Cotton thread, wound round bulb.	852
Lint, loose.	1032
Linen thread, wound round bulb.	873
Linen cloth, ditto.	786

From these experiments, Rumford showed that the heat-retaining value of clothing depends more on its texture than on its actual material. For further consideration of this subject, see Matticu Williams' book on *The Philosophy of Clothing.*

* The general term "asbestos" includes the fibrous varieties of both pyroxene and hornblende. Pyroxene is a compound silicate of magnesium and calcium, always containing iron, and generally also some manganese. Hornblende (also known as amphibole) is very similar in composition, but often contains aluminium.

† The individual fibres of asbestos are so fine as to approach the limits of microscopic measurement which is $\frac{1}{2}\mu = 0.0005$ mm.

towards a greenish color. The fibres of some varieties (Canadian) are curly, and afford the best material for spinning.* In general, however, the fibres of asbestos are straight and glassy in structure, and are difficult to spin into a coherent thread. In order to enhance its spinning qualities it is mixed with a little cotton or linen, the latter fibre being subsequently destroyed by heating the woven fabric to incandescence. By improved methods of handling, however, it is now possible to spin asbestos directly without admixture with cotton; the asbestos is first softened

FIG. 3.—Asbestos Fibre. ($\times 5$.) (Micrograph by author.)

in hot water and then disintegrated mechanically into the fibre. At the present time quite a variety of fabrics are manufactured from asbestos fibre, and the high quality of many articles appearing

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* Asbestos occurs in a variety of species, some of which are much more valuable than others for fibre purposes. In some the fibres are slender and easily separable, and of a white or greenish color. A variety known as *Amianthus* gives fibres of a fine silky quality. Ligniform asbestos is a hard compact variety, resembling petrified wood in appearance, and brownish to yellowish in color; a wool-like variety found near Vesuvius is known as *Breislakite*. A variety of serpentine also yields an asbestos, but of inferior quality; it differs from the hornblende variety in that it contains about 14 per cent. of water in its composition. The mineralogical name for this fibrous variety of serpentine is *chrysotile*. Canadian asbestos is the most valuable as a source for textile purposes, as it yields a curly fibre easily spun into threads.

on the market shows that the art of manipulating this substance
has reached a high degree of perfection.   On account of its
incombustible nature, and as it is a very poor conductor of heat,
it is made into fabrics where these qualities are especially desired.
Thus it is frequently manufactured into gloves and aprons, packing
for steam-cylinders, theatrical curtains and scenery, lamp-wicks,
etc.   The latter use of asbestos was known to the ancients, who
employed it for the wicks of the perpetual lamps in their temples.
It is from this fact, indeed, that it received its name, the word
"asbestos" meaning "unconsumed."   It was also employed for
napkins on account of its being readily cleansed, it only being
necessary to heat the fabric in a flame to make it clean again.
In some cases asbestos is spun directly around a copper wire for
purposes of insulation.   Asbestos, in general, is not dyed, and
does not undergo any chemical processes or modes of treatment.
When it is desirable to dye it the various substantive dyes may
be used with good effect, or the color may be applied by mordant-
ing with albumen.

The **artificial fibres** may be divided into two groups: (*a*)
those of mineral origin and (*b*) those of animal or vegetable
origin.   In the first division may be classed such fibres as spun
glass, metallic threads, and slag wool; in the second division
may be put the various artificial silks, such as lustra-cellulose
and gelatin silk.

Fibres of **spun glass** are prepared by drawing out molten
glass in the form of very fine threads; * colored glasses may be used
to give rise to variously colored threads.   Owing to its brittle
nature and lack of elasticity, spun glass receives a very limited
application, it being made into various ornamental objects, and
sometimes into cravats.†   A variety of spun glass known as *glass
wool* is used to some extent in the chemical laboratory as a filter-
ing medium for liquids which would destroy ordinary filter-paper.

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* Glass threads can be drawn out so fine that it takes about 1400 miles of
the fibre to weigh one pound.

† Though fabrics composed of glass are rare, yet colored glass threads are
somewhat used for the weft in silk materials for the purpose of producing novel
effects, as the glass gives the fabric great lustre and stiffness.

Glass wool is curly, this property being given to it by drawing out the glass thread from two pieces of glass of different degrees of hardness; and by unequal contraction on cooling, this double thread curls up.

Various metals are at times drawn out into threads for use in decorative fabrics. Gold, silver, copper, and various alloys are used for this purpose, the metals being heated to redness or until they are in a softened condition. At the present time metallic threads are largely imitated by coating linen yarns with a thin film of gold or silver. Threads of pure gold are seldom made; what is known as " pure-gold " thread is a fine silver wire covered with a thin layer of gold. Silver thread is sometimes made with a core of copper and a layer of silver. Lyon's gold thread consists of copper faced with gold. Metallic threads are usually made into a flattened or band-like form by rolling; by twisting with silk or woolen yarns, the so-called "brilliant" yarns are made. The Cyprian gold thread of old embroideries consists of a linen or silk thread around which is twisted a cover of gilded catgut.

Metallic threads are used for quite a large number of fabrics, such as passementerie work, trimmings, brocades, decorative embroidery, church vestments, fancy costumes, tapestries, fancy vestings, etc.

Slag wool is prepared by blowing steam through molten slag; it can scarcely be called a textile fibre, but it is used in some degree as a packing material.

Artificial silks are made either from cellulose derivatives or gelatin by forcing solutions of these through fine capillary tubes, coagulating the resulting threads, and subsequently subjecting them to various processes of chemical treatment. As these belong more strictly to the class of true textile fibres, they will be given a more extensive consideration, in a further section, as being derivatives of cellulose.*

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* *Artificial cotton* is made from pine wood. The latter is cut up into shavings and reduced to the fibre, which is then steamed and boiled under pressure with caustic-soda solution.

CHAPTER II.

1. The Sheep.—The woolly, hair-like covering of the sheep forms the most important and the most typical of the textile fibres which are obtained from the skin tissues of different animals. The hairy coverings of a large number of animals are employed to a greater or lesser extent as raw materials for the manufacture of different textile products, but those of the various species of sheep make up the great bulk of the fibres which possess any considerable technical importance. Hairs, derived from whatever species of animals, have very much in common as to their general physical and chemical properties; they are also similar with respect to their physiological origin and growth. The hairs, however, of different animals vary much in the detail of their special characteristics, and also with regard to their adaptability for use in the textile industry; and the wool of the sheep appears to exhibit in the highest degree those specific properties which make the most suitable textile fibre. These properties may be enumerated as being: (*a*) Sufficient length, strength, and elasticity, together with certain surface cohesion, to enable several fibres to be twisted or spun together so as to form a coherent and continuous thread or yarn; (*b*) the power of absorbing coloring-matters from solution and becoming dyed thereby, and also the property of becoming decolorized or bleached when treated with suitable chemical agents; (*c*) in addition to these qualities, which they have in common with almost any textile fibre, wool fibres also possess the quality of becoming felted or matted together, due to the peculiar physical character of their surfaces. This property is a most valuable one, as it

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adapts wool to a large number of uses to which other fibres are unsuitable.

Silk is also a member of the general group of animal fibres, and though it possesses certain general chemical characteristics in common with wool and hair, yet it has an entirely different physiological origin, being a filament of animal tissue excreted by a certain species of caterpillar, and hence is totally different from wool in its physical properties. There is also a distinct chemical difference in wool and silk. The former contains sulphur as an essential constituent, while the latter contains no sulphur in its composition. Wool may be specifically designated as a variety of hair growing on certain species of mammalia, such as sheep, goats, etc. The unmodified term "wool" has special reference to the product obtained from the different varieties of sheep. Cashmere, mohair, and alpaca are the products obtained from the thibet, angora, and llama goats, respectively. Fur is also a modified form of hair, but differs from wool in many of its physical properties,* and is not adapted for use in the manufacture of spun textiles. It is, however, largely employed for the making of hat felts.†

The wool-bearing animals all belong to the order *Ruminantia*, which includes those animals that chew their cud or ruminate. The principal members of this order are sheep, goats, and camels. The sheep belongs to the class *Ovidæ*, and occurs in a number of species which vary considerably in form and geographical distribution, as well as in the character of the wool it produces. Broadly considered, naturalists divide the sheep into three different classes:

(*a*) *Ovis aries*, commonly known as the domestic sheep, and cultivated more or less in every country in the world.

(*b*) *Ovis musmon*, occurring native in the European and African countries bordering on the Mediterranean Sea.

(*c*) *Ovis ammon*, which includes the wild or mountain sheep

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* The cross-section of wool is almost circular, while that of fur is quite elliptical.

† The fur of the hare, rabbit, and cat is occasionally mixed with cotton, wool, or waste silk and spun into yarns. Such yarns are principally used for the weaving of certain kinds of velvets.

(*argali*) to be found in Asia and America.   The big-horn sheep of the Rocky Mountains belongs to this class.*

The domestic sheep is the most important of these classes. It can hardly be said to be indigenous to any one country, for it

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* A more detailed classification than the above is given by Archer, who divides the sheep into thirty-two varieties:

1. Spanish, or merino sheep (*Ovis hispaniam*).
2. Common sheep (*Ovis rusticus*).
3 Cretan sheep (*Ovis strepsiceros*).
4. Crimean sheep (*Ovis longicaudatus*).
5. Hooniah, or black-faced sheep of Thibet.
6. Cago, or tame sheep of Cabul (*Ovis cagia*).
7. Nepal sheep (*Ovis selingia*).
8. Curumbar, or Mysore sheep.
9. Garar, or Indian sheep.
10. Dukhun, or Deccan sheep.
11 Morvant de la chine, or Chinese sheep.
12. Shaymbliar, or Mysore sheep.
13 Broad-tailed sheep (*Ovis laticaudatus*).
14. Many-horned sheep (*Ovis polyceratus*).
15. Pucha, or Hindoostan dumba sheep.
16. Tartary sheep.
17. Javanese sheep.
18. Barwall sheep (*Ovis Barnal*).
19. Short-tailed sheep of northern Russia (*Ovis brevicaudatus*).
20. Smooth-haired sheep (*Ovis Ethiopia*).
21. African sheep (*Ovis Grienensis*).
22 Guinea sheep (*Ovis ammon Guinensis*).
23 Zeylan sheep.
24. Fezzan sheep.
25. Congo sheep (*Ovis aries Congensis*).
26. Angola sheep (*Ovis aries Angolensis*).
27 Yenu, or goitred sheep (*Ovis aries steatiniora*).
28. Madagascar sheep.
29. Bearded sheep of west Africa.
30. Morocco sheep (*Ovis aries muncædæ*).
31. West Indian sheep of Jamaica.
32. Brazilian sheep.

These represent the naturally occurring classes of sheep in the different countries; of course, a large number have been emigrated and domesticated in other countries than those in which they had their origin, which has given rise to several sub-varieties.   Then, too, new varieties have been formed by cross-breeding and intermixing, which has brought about a considerable variation in the type. The latter is also influenced very largely by climatic conditions, geographical environment, and character of pasturage.

appears to have been cultivated by the earliest peoples in history, and it has spread over the entire face of the globe with the gradual extension of civilization itself. Different conditions of climate and soil, of pasturage and cultivation, appear to exert a considerable influence on the variety of the sheep and on the character of the wool it eventually produces. Variations are also produced by cross-breeding and intermixing, and the nature of the fibre has been much altered and improved by careful selection in breeding and genealogical development.

Sheep in their natural condition produce two kinds of hair: the one giving a long, stiff fibre, which we will call "beard-hair"; and the other a shorter, softer, and more curly fibre, which we will designate as "wool-hair," or true wool. By domestication and proper cultivation the sheep can be made to produce the latter kind of hair almost exclusively, with but little or none of the hairy fibre. Herein the sheep differs essentially from the goat, as the latter will always produce both kinds of fibre, though the fineness and quality of its hair may be much improved by proper cultivation. In addition to the above-mentioned varieties of hair, most sheep grow more or less of short, stiff hairs, or undergrowth; these have no value as textile fibres. It must be mentioned, however, that the exact character of the wool on the individual sheep varies considerably with its position in the fleece; on the extremities of the animal the wool becomes more hairy in nature, and near the feet the short undergrowth of stiff hair is alone to be found. The texture, length, and softness of the fibre also differ considerably in different portions of the fleece.* Hence it becomes necessary, in order to obtain a homogeneous mixture of fibres with properties as constant as possible, to sort out the fibres of the fleece into different portions, which are put together into different grades of wool stock. This operation is termed wool-sorting and grading, and is an important step in the manufacture

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* In well-cultivated sheep the wool-hairs are usually united in *tufts* or *locks* containing a hundred or more fibres. Often several locks are connected into one large one called a *staple*, the hairs joining the locks together being known as *binders*. The number of hairs growing on each square inch of the sheep's skin is between 4,500 and 5,500.

of wool. Different varieties of wool may require different systems and degrees of sorting, but in general the fleece is roughly divided into nine sections, given as follows:

(1) The shoulders and sides of the fleece give the finest and most even staples of fibre.

(2) The lower part of the back yields a fibre of fairly good staple.

(3) The loin and back give a shorter staple, and the fibre is not as strong.

(4) The upper part of the legs give a staple of moderate length. The fibre on this part is frequently in the form of loose, open locks and acquires a large amount of burrs by brushing against the spinose fruit of the plant; the presence of these burrs considerably lessens the commercial value of the wool. South American wool is especially liable to be heavily charged with burrs.

(5) The upper part of the neck gives a rather irregular staple which is also very frequently filled with burrs.

(6) The centre of the back gives a fine delicate staple similar to that from the loins.

(7) The belly, together with the wool from the fore and hind legs, yields a poor staple and a weak fibre.

(8) The tail gives a short, coarse, and lustrous fibre, frequently containing a considerable amount of kemps.

(9) The head, chest, and shins give a short, stiff, and straight fibre, opaque and dead white in color.

The merino sheep, which yields what is considered to be the finest quality of wool, appears to have originated in Spain, and at one time was extensively cultivated by the Moors. The exportation of merino sheep from Spain was long guarded against with great care, no one being allowed to take a live merino sheep out of the kingdom of Spain under penalty of death. Later, however, this sheep was brought into various countries, being crossed with the different local breeds with very beneficial results. A German derivative of the Spanish merino known as the Saxony Electoral merino, gives perhaps the highest grade of fibre known in Europe. Australian sheep are mostly derived from merino,

and other high-class stock and yield a wool of the very highest quality. The merino has been cultivated and crossed with other breeds throughout the various parts of the United States, and the latter country is gradually becoming a large producer of middle-grade wool.*

The amount of fibre in the fleece varies greatly with the breed, sex, age, and racial conditions of the animal. The average yield from the ewe is 1.75 to 4 lbs., and from the wether 3.5 to 7.5 lbs.

2. Physiology and Structure of Wool.—Wool, in common with all kinds of hair, is a growth originating in the skin or cuticle of the vertebrate animals, and is similar in its origin and general composition to the various other skin tissues to be found in animals, such as horn, nails, feathers, etc. Wool is an organized structure growing from a root situated in the dermis or middle layer of the skin, its ultimate physical elements being several series of animal cells of different forms and properties. Herein it differs essentially from silk, which is not composed of cells, but is a continuous and homogeneous tissue. The root of the wool fibre is termed the **hair follicle** (Fig. 4); it is a gland which secretes a lymph-like liquid, from which the hair is gradually developed by the process of growth. The hair follicle also secretes an oil, which is supplied to the fibre during its growth and serves the purpose of lubricating its several parts, giving it pliability and elasticity. In conjunction with the hair follicle there also occur in the skin numerous sebaceous glands which secrete a fatty or waxy substance, commonly known as **wool-fat**. This substance gradually exudes from the glands and coats the surface of the

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* According to the National Association of Wool Manufacturers, the wool clip for 1905 in the United States amounted to 295,488,438 pounds; during the same year the net imports of wool were 242,471,489 pounds, giving a total supply of 632,331,459 pounds.

The imports of manufactures of wool for 1905 amounted in value to $21,373,-742, and estimating three pounds of wool in the grease for each dollar in value, we reckon that in the form of manufactured goods there were imported in this year 64,121,226 pounds, which added to the takings of domestic mills (478,667,-887) amounted to 542,789,113 pounds of wool as approximately representing the consumption of wool by the American people in the way of domestic and foreign manufactures, which, distributed on the basis of the population, amounted to 6.54 pounds of wool per capita required to meet consumptive demand.

wool in rather considerable amount (Fig. 5). It affords a pro-
tective coating to the fibre which serves to preserve the latter from
mechanical injury during its growth, and also prevents the sev-
eral fibres from becoming matted and felted together. In the
preparation of wool for manufacture, this fatty covering has to be
removed, the operation constituting the ordinary process of wool-
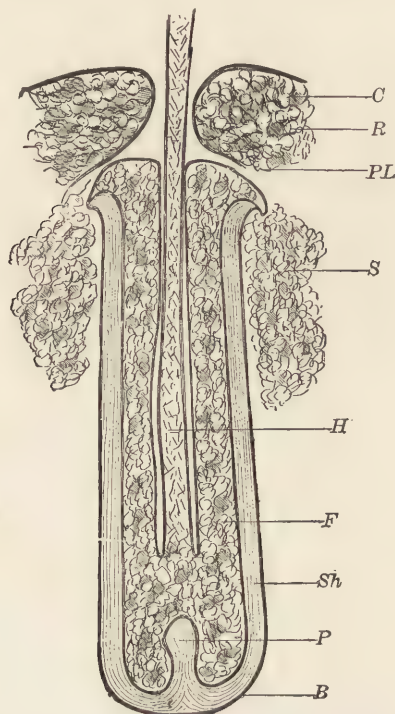
FIG. 4.—Section of Hair Follicle. (×100.)

C, cuticle of skin; R, reta mucosum; PL, papillary layer; S, sebaceous glands;
P, papilla; B, bulb of hair; H, hair; F, fibrous tissue; SH, transparent
sheath. (Micrograph by author.)

scouring. There is also a **wool-oil** which is contained in the cells
of the fibre itself, and is a true constituent of its substance.
This oil should not be removed, as its removal causes the fibre to
lose much of its elasticity and resiliency. The oil amounts to
about 1 per cent. of the total weight of the fibre, whereas the
external fatty matters amount on an average to about 30 per cent.

FIG. 5.—Wood Fibre in the Grease. (×500.)

A, irregular lumps of grease and dirt; also note that outline of scales is very indistinct. (Micrograph by author.)

FIG. 6.—Typical Wool Fibres after Removal of Grease. (×350.)
(Micrograph by author.)

Morphologically considered, the wool fibre consists of three distinct portions: (*a*) A cellular marrow, or **medulla,** which frequently contains more or less pigment matter to which the wool owes its color; (*b*) a layer of cellular fibrous substance or **cortical tissue** which gives the fibre its chief strength and elasticity;
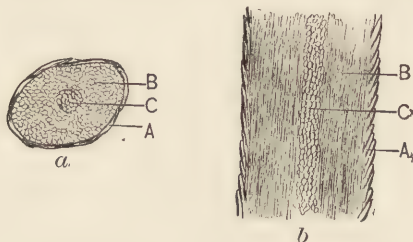
FIG. 7.—Sections of a Hair Fibre.   (×500.)

a, cross-section; *b*, longitudinal section; *A*, epidermal layer of scales; *B*, cortical layer of fibrous cells; *C*, medullary layer of round cells.
(Micrograph by author.)

(*c*) an outer layer, or **epidermis,** of horn tissue, consisting of flattened cells, or scales, the ends of which generally overlap each other, and project outwards, causing the edge of the fibre to present a serrated appearance (Fig. 7). This scaly covering gives the fibre its quality of rigidity and resistance to crushing
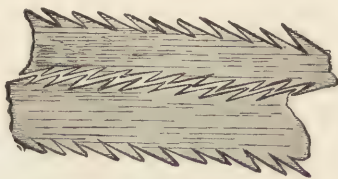
FIG. 8.—Diagram showing Felting Action of Wool.   (Drawing by author.)

strain; it also causes the fibres to felt together on rubbing against one another by the interlocking of the projecting edges of the scales (Fig. 8).

Any one of these three physical constituents may at times be lacking in a fibre. When the epidermal scales are absent, they have simply been rubbed off by friction; this condition is frequently to be found at the ends of long beard-hairs. The cortical layer of fibrous tissue is frequently but slightly developed, espe-

cially in cases where the medulla is large : in some instances, indeed (as in the hair of the doe), the cortical layer appears to be totally absent in the broadest parts of the fibre. The medulla is very frequently absent, or, at least, shows no difference in structure from the cells of the surrounding cortical layer (Fig. 10); this occurs more especially in the wool-hairs, but is also to be found in beard-hairs. On the other hand, the medulla is occasionally more largely developed than the cortical layer, and becomes the
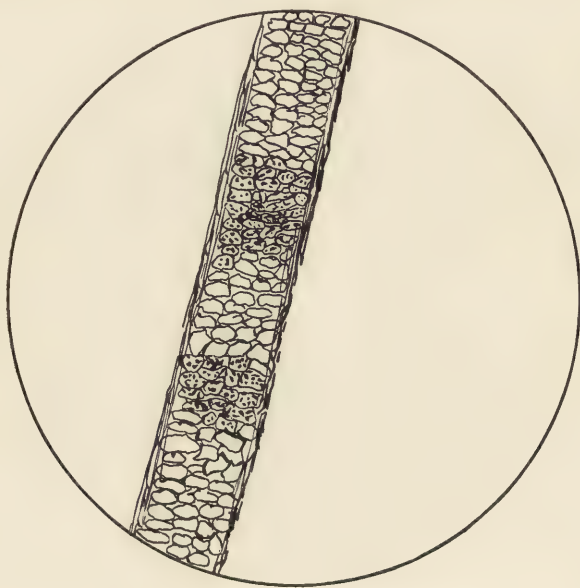
FIG. 9.—Beard-hair of Doe. (×350.)
Showing small development of cortical layer and large medulla.
(Micrograph by author.)

principal part of the fibre, as in the beard-hairs of the doe (Fig. 9).

The **microscopic appearance** of wool is sufficiently character-istic to distinguish it from all other fibres. Under even moder-ately low power of magnification the **epidermal scales** on the sur-face of the fibre can be readily discerned, while neither silk nor the vegetable fibres present this appearance (Fig. 11). The scales are more or less translucent in appearance, and permit of the

under cortical layer being seen through them. The exact nature
and structure and arrangement of the scales differ considerably
with different varieties of wool. In fine merino wools, for in-
stance, the individual scales are in the form of cylindrical cusps,
one somewhat overlapping the other; that is to say, a single
scale completely surrounds the entire fibre (Fig. 12, *M*). In some
varieties of wool, on the other hand, two or more scales occur in
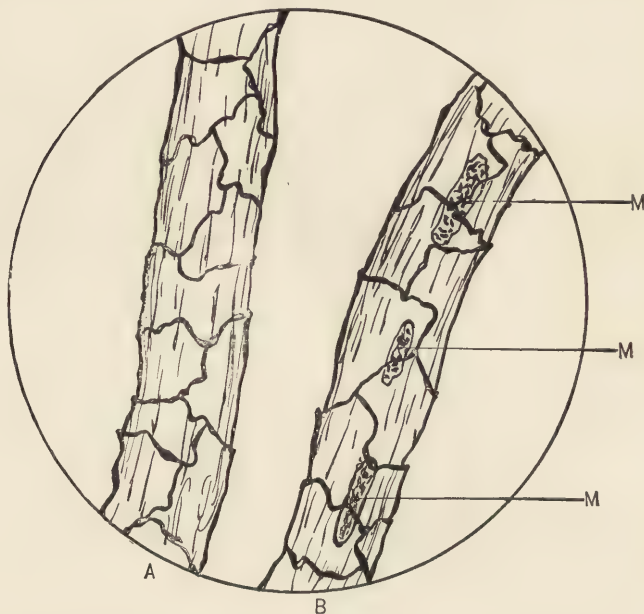
FIG. 10.—Wool Fibres Deficient in Medullary Cells. (×500.)
A, a fibre without evidence of medullary cells; *B*, a fibre showing isolated medul-
lary cells at *M*. (Micrograph by author.)

the circumference of the fibre (Fig. 12, *T*). In some cases the
edges of the scales are smooth and straight, and this appears to
be especially characteristic of fine qualities of wool; the coarser
species, on the other hand, possess scales having serrated wavy
edges. Usually such scales are much broader than they are
long and are very thin. The length of the free or projecting
edge of the scale is also a very variable factor; in some wools the
scale is free from the body of the fibre for about one-third of the

length of the former, and in consequence the scale protrudes to a considerable extent; such wool would be eminently suitable for the preparation of material which requires to be much felted (Fig. 12, *M*). In other wools the free edge of the scale amounts to almost nothing, and the separate members fit down on one another closely, and are arranged like a series of plates. Wools of this class are more hair-like in texture, being stiffer and straighter,
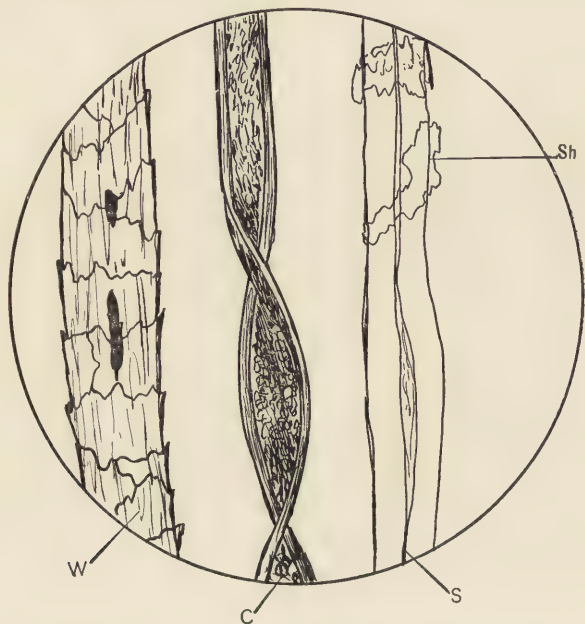
Fig. 11.—Comparison of Wool, Cotton, and Silk Fibres. (×500.)
W, wool fibre, showing marking of scales; *C*, cotton; *S*, silk, showing irregular shreds of silk-glue at *Sh*. (Micrograph by author.)

and not capable of being readily felted (Fig. 13). The wool-hairs (the long, stiff fibres which have already been mentioned as occurring to a greater or lesser degree in nearly all wools and also known as beard-hairs) usually possess this structure. The felting quality of wool is much increased by treatment with acid or alkaline solutions, or even boiling water, the effect being to open up the scales to a greater extent, so that they present a much larger free margin and consequently interlock more readily and

firmly. Woolen yarns, and woven materials made from such
yarns, felt much more easily than worsted yarns, due to the fact
that the fibres of the former lie in every direction and the inter-
locking of the scales takes place more easily.

In some varieties of wool fibre the scales have no free edge at
all, but the sides fit tightly together with apparently no overlap-
ping; in such fibres the surfaces of the scales are also more or
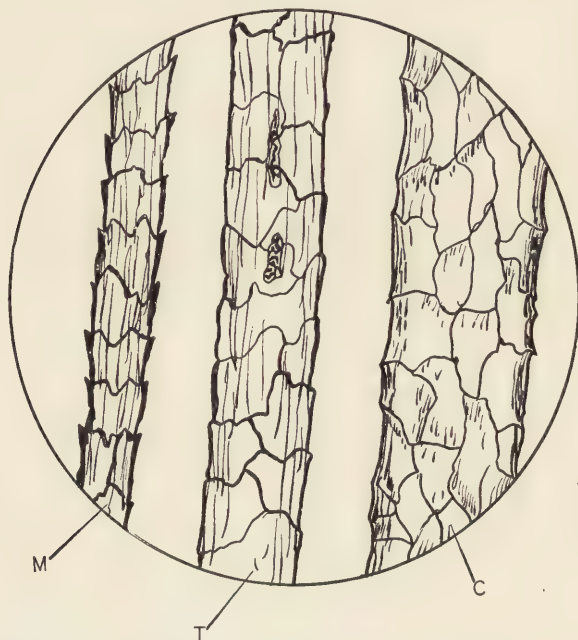
FIG. 12 —Comparison of Different Varieties of Wool. (× 500.)
M, merino wool with only a single scale in circumference of fibre; *T*, territory
wool with two or more scales; *C*, coarse wool with numerous scales
(Micrograph by author.)

less concave (Fig. 14).   This structure only occurs with thick,
coarse varieties of wool.   Frequently at the ends of the wool
fibre, where the natural point is still preserved (as in the case of
lamb's wool from fleeces which have not been previously sheared),
the scales are more or less rubbed off and the under cortical
layer becomes exposed (Fig. 15, *P*); this appearance is quite char-
acteristic of certain wools.   In diseased fibres the epidermal scales

may also be lacking in places, causing such fibres to be very
weak at these points (Fig. 15, *D*).

In most varieties of wools the scales of the epidermis may be
readily observed even under rather low powers of magnification,
while under high powers the individual scales may be seen over-
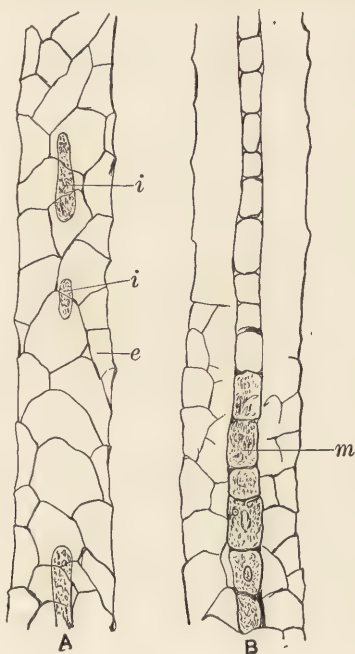
FIG. 13.   FIG. 14.

FIG. 13.—Wool Fibre with Plate-like Scales.   (×340.)   (Höhnel.)
A, portion of fibre with isolated medullary cells at *i*, and smooth scales *e* fitting
together like plates; *B*, portion of fibre showing medullary cylinder at *m*.

FIG. 14.—Wool Fibre with Concave Scales.   (×340.)   (Höhnel.)
m, medullary cylinder consisting of several rows of cells; *e*, concave scales arranged
in a plate-like manner.

lapping one another like shingles on a roof, and showing pointed,
thickened protuberances at the edges.   When the fibre becomes
more hair-like in nature, such as mohair, alpaca, camel-hair, etc.,
it is more difficult to observe the individual scales, as these fuse
together to a greater or lesser degree, until the true hair fibre
is reached, which exhibits scarcely any markings of scales at

THE TEXTILE FIBRES.

all under ordinary conditions. By treatment with ammoniacal copper oxide, however, the interscalar matter is dissolved away, and even with true hair the scaly nature of the surface may be
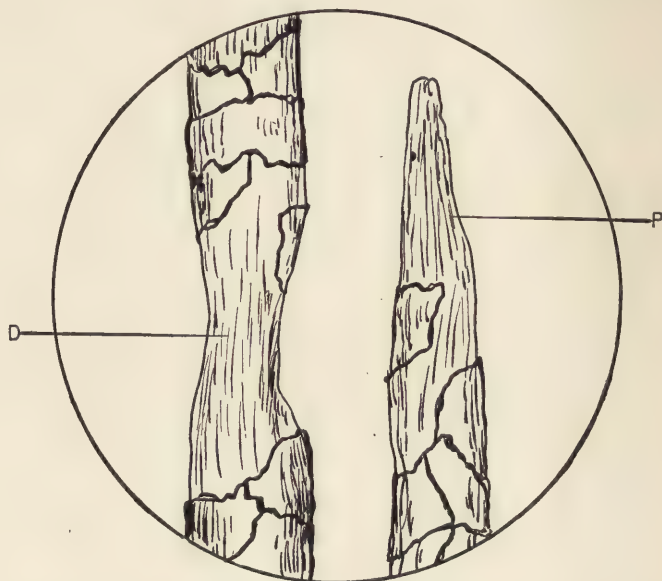
FIG. 15.—Wool Fibres showing Absence of Epidermal Scales. (×500.)

D, at middle portion of fibre, probably due to disease; *P*, at point of fibre of lamb's wool. (Micrograph by author.)

observed. Bowman gives the approximate comparative number of scales per inch in different varieties of wool as follows:

Wool.	Scales, per inch.	Diam. of Fibre (ins.).
East Indian	1000	0.00143
Chinese	1200	0.00133
Lincoln	1400	0.00091
Leicester	1450	0.00077
Southdown	1500	0.00080
Merino	2000	0.00055
Saxony	2200	0.00050

According to the measurements of Hanausek, the size of the epidermal scales on different forms of hair fibres are as follows:

Fibre.	No. of Epidermal Scales per mm. Length of Fibre.
Sheep's wool, ordinary....................	97
" " merino...................	114
" " Electoral	100
" " Saxony................	121
Angora wool........................	53
White alpaca	90
Brown alpaca.......................	150
Vicuña wool........................	100
Camel's wool.......................	90

The **epidermal layer** of scales imparts to the wool fibre its characteristic quality of **lustre**. Since the lustre of any surface is due to the unbroken reflection of light from that surface, it may be readily understood that the smoother the surface of the fibre, the more lustrous it will appear When the epidermal scales are irregular and uneven, and have projecting points and roughened edges, the surface of the fibre will naturally not be very smooth and uniform, and consequently will reflect light in only a broken and scattered manner. Such fibres will not have a high degree of lustre. On the other hand, when the scales are regular and uniform in their arrangement, and their edges are more or less segmented together to form a continuous surface, the fibre will be smooth and lustrous. As a rule, the coarser and straighter fibres are the more lustrous, as they approximate more closely to the structure of hair, which has a smooth surface. The lustre of the fibre being dependent on the polished surface of the scales is influenced largely by any condition which may affect the latter. Treatment with chemical agents, for instance, which will corrode the horny tissue of the scales will seriously affect the lustre, as is evidenced by allowing alkaline solutions to act on lustrous wool fibres. High temperatures (and especially dry heat) corrodes the epidermal scales and shrivels them up, causing the fibre to lose its lustre. In the various mechanical processes through which the wool must pass in the course of its manufacture, the scales of the fibre suffer more or less injury, being torn apart, roughened, and loosened from the surface. In order to minimize the extent of this injury the wool is generally oiled, so that the surface of the fibres may be properly lubricated.

The **rigidity** and **pliability** of the wool fibre is also largely conditioned by the nature of its epidermal scales. If these fit over one another loosely with considerable length of free edge, the fibre will be very pliable and plastic, soft, and yielding, also easily felted. Whereas, if the scales fit closely against one another and have little or no freedom of movement, the fibres will be stiff and resistant, and not easily twisted together nor felted.

The **cortical layer**, or true fibrous portion of the fibre, forms the major constituent of wool. It consists principally of more or less elongated cells, and often presents a distinctly striated appearance, the striations being visible through the translucent layer of scales. The individual cells measure from 0.0014 inch to 0.0025 inch in length, and from 0.00050 inch to 0.00066 inch in diameter, hence are elliptical in form. The cells may be disintegrated from one another by a careful treatment with caustic alkali. To this cortical tissue the fibre chiefly owes its tensile strength and elasticity. When the fibre is fine in staple, the cortical cells exhibit more or less unevenness in their growth and arrangement, with the result that the fibre is contracted on one side or the other, giving rise to the **waviness** or curled appearance of such wools. It is best, perhaps, to speak of the wool being "wavy" rather than "curled," as the latter implies usually a spiral development which involves a twisting of the fibre, and in wool, as a rule, this does not occur. Coarse wools seldom exhibit this wavy structure, or only to a slight degree, the waves being long and irregular; some fine stapled wools, on the other hand, possess short and very regular waves. This property of the fibre adds much to its spinning qualities, and also to the resiliency of the yarn or fabric into which it is manufactured. Wool-hairs exhibit much less development of waves than the true wool fibres, and the more closely the animal fibres approximate to the structure of ordinary hair, the less pronounced are the waves. Sheep's wool is more wavy than that derived from allied species, such as the various goats, camel, etc. Mohair, for instance, exhibits no wavy structure at all. The exact cause which determines the wavy quality of wool is but ill-defined; there appears, however, to be some connection between the degree of curl, the diameter of the fibre,

and the number of scales per inch. The following table, given by Bowman, shows the relation between the number of waves and the diameter of the fibre.

Wool.	Waves per inch.	Diameter of Fibre (ins.).
English merino........................	24–30	0.00064
Southdown.	13–18	0.00078
"	11–16	0.00100
Irish................................	7–11	0.00120
Lincoln.	3–5	0.00154
Northumberland.	2–4	0.00172

The waviness of the wool fibre may be temporarily removed by wetting with hot water and drying while in the stretched condition.

In **tensile strength** and **elasticity**, the wool fibre varies within large limits, depending on the breed and quality of the sheep, and also the diameter of the fibre and the part of the fleece from which it was derived. The strength of wool, and of animal hairs in general, is due to the peculiar structure of the fibre. In the first place, the external sheath of horny tissue of flattened cells which take the form of scales, offers considerable resistance to crushing strains, and are also locked rather firmly together in the direction of the length of the fibre; this has a tendency to resist any diminution in the diameter of the fibre which would be felt when the latter is stretched. Then, too, the internal cortical cells of the fibre are so arranged as to present a very firm structure, being firmly interlaced together, consequently they offer considerable resistance to rupture. It has been noticed by a microscopical examination of a broken fibre that the cells themselves are never ruptured, but only pulled apart from one another; this is evidence that the cell-wall is of a strong texture. The latter is probably formed of a continuous tissue which is less than 0.0002 inch in thickness, as under the highest powers of the microscope it exhibits no evidence of structural elements. Bowman gives the following table, which records the average results of a number of experiments on the strength and elasticity of the wool fibre:

Wool.	Tensile Strength, grams.	Elasticity, per cent.	Diameter, ins.
Human hair.	106	36.6	0.00332
Lincoln wool.	33	28.4	0.00181
Leicester.	31	27.3	0.00164
Northumberland.	28	27.0	0.00149
Southdown wool.	5.9	26.8	0.00099
Australian merino.	3.2	33.5	0.00052
Saxony merino.	2.5	27.5	0.00034
Mohair.	38	29.9	0.00170
Alpaca.	9.7	24.2	0.00053

It is interesting to compare these figures of tensile strength for equal cross-sections of fibre. As the cross-section varies with the square of the diameter, by taking the ratio of the latter numbers and multiplying by the tensile strength, a figure is obtained which represents the tensile strength for equal diameters of fibres. In this manner the following table has been calculated, taking human hair as the standard for comparison, as it has the largest diameter:

Human hair.	100
Lincoln wool.	96.4
Leicester.	119.9
Northumberland.	130.9
Southdown wool.	62.3
Australian merino.	122.8
Saxony merino.	224.6
Mohair.	136.2
Alpaca.	358.5
Cotton (Egyptian).	201.8

It will be noticed from this table that Saxony merino wool is by far the strongest of the different grades of wool. It is also interesting to note that cotton is considerably stronger than the majority of wools.

The **medulla,** or marrow, of the wool fibre consists of round or slightly flattened cells, usually somewhat larger in section than those comprising the cortical layer (Fig. 7, *C*). The size of the medulla varies considerably in different varieties and grades of wool, and even shows large variations in fibres from the same fleece. At times it may occupy as much as one-quarter to one-third of the entire diameter of the fibre; and again, it may be

reduced to almost a line, or even disappear completely. Wool-hairs exhibit the presence of a distinct medulla more frequently than the true wool fibres. The latter mostly show scarcely any inner structure at all, though at times there may be noticed isolated medullary markings, but usually the fibre is so transparent that it presents no markings at all. In camel-hair, however, the medullary portion shows up very distinctly, in some fibres appearing as a continuous dark band occurring about three-fourths of the width of the fibre, while in other fibres it shows a well-defined granular structure. In hairs of some other animals the medullary part exhibits a structure which is distinctly characteristic of the fibre; in the hair of the cat, for instance, the medullary cells appear in a reticulated form, and in the hair of the rabbit they occur as a series of laminæ very regularly superposed on each other. The medullary cells frequently contain **pigment matter,** either continuously or in isolated cells; and this may occur even in fibres usually classified as white wool. Sometimes the pigment permeates not only the medulla, but also the cells of the cortical layer, in which case the fibre as a whole appears colored. To this class belong the variously colored wools, ranging from a light brown to almost a black. The hair of camels, goats, and other animals is also more or less colored, and to a much more general extent than sheep's wool. The medulla may consist of a single series of çells, or of several series arranged side by side; sometimes these cells occur in a discontinuous and rather irregular manner, the intervening spaces of the medulla being filled with air. The function of the medulla is to provide the living fibre with an inner canal for the flow of juices whereby it receives nourishment for its growth. It also adds much to the porosity of the fibre, forming a capillary tube whereby the latter may suck up solutions of various kinds, such as dyestuffs, different salts, etc., allowing these to gradually permeate through the cortical layer as well. The epidermal layer of scales is rather impervious to the transpiration of solutions, and only permits of their entrance into the fibre at the joints of the scales, so it may be seen that the medulla of the fibre becomes an important adjunct in the chemical treatment of wool in the processes of mordanting,

dyeing, and bleaching. It might also be noted, in this connec-
tion, that the epidermal scales become but slightly, if at all,
dyed when various coloring-matters are applied to the fibre, but
remain clear and translucent. Hence it may be readily under-
stood that if two samples of wool are dyed simultaneously, the
one consisting of fibres having small and open scales, while the
other has a thick and highly resistant epidermis, the resulting
color on the two samples will have a different quality or tone,
due to the influence on the latter of the uncolored and trans-
lucent scales. In wools where this influence is very marked it is
almost impossible to obtain rich and full shades of color, due to
the transparency and lustre of the surface, which allows of con-
siderable white light being refracted through the fibre along
with the reflected color. This also explains the well-known fact
that the longitudinal surface of the fibre in many cases presents
a different tone of color than the cut ends, the latter usually being
richer and deeper in tone; as may be noticed in cut-pile fabrics,
such as occur in rugs, plushes, etc. In some cases the epidermal
layer, instead of being highly translucent, is opaque and white;
this is true of many varieties of coarse wool-hairs, and such fibres
as cow-hair, etc. In such instances the dyed fibre will lack
liveliness of tone and appear rather dead and flat. The further
discussion of this interesting subject must be dealt with in more
detail in the study of shade matching. Attention is merely called
to it at this point in order to emphasize more clearly the funda-
mental cause of these differences in color phenomena as lying
in the st ucture of the fibre itself.

Frequently, through disease or other natural causes, the
medulla of the wool fibre is imperfectly developed, in consequence
of which the wool will not absorb solutions readily, and hence
will not be dyed (or mordanted) at all, or only slightly. These
fibres, which are known as **kemps**, will occur through the mass
of the wool as undyed streaks, and will give the yarn or fabric a
speckled appearance. Not only may this condition, however,
be brought about by natural causes, but it may at times be the
result of improper manipulation during manufacturing processes.
There is a certain class of wool, for instance, known in trade as

pulled wool; * this is obtained from the pelts of slaughtered sheep, and is usually removed from the skin by the action of lime, the fibres being pulled out by the roots. In the process, the medulla becomes stopped up with solid insoluble particles of lime, which is also true of the end pores of the cortical layer and the joints of the scales. As a consequence, the fibre is very difficult to impregnate with solutions, and will remain more or less completely undyed. This non-porous character is also enhanced, perhaps, by the fact that the fibre does not possess a freshly cut end, but still retains the root, which is more or less rounded off and closed by the coagulation and hardening of the juices in the hair follicle.

The medulla, as a rule, is more developed in beard-hairs than in wool-hairs, and more in coarse grades of wool than in the finer qualities. There also appears to be more or less relation between the breed of the wool and the morphological characteristics of the medullary cells, although this is a subject which as yet has been but little studied. At times the medullary cells exhibit but little differentiation from those of the cortical layer, and these two portions of the fibre become continuous in their appearance, that is to say, no line of demarcation can be drawn between the medulla and the surrounding cortical layer.

In **length**, the wool fibre varies between large limits, not only in different sheep, but also in the same fleece. Generally speaking, the length may be taken as being between 1 and 8 inches. The **diameter** of the fibre is also very variable, even in the same fleece, but may be taken as averaging from 0.0018 to 0.004 inch.† According to their length of staple, wool fibres are graded into two classes: **tops** and **noils**. The former includes the longer stapled fibres, which are **combed** and spun into **worsted** yarns, to be manufactured into trouserings, dress-goods, and such fabrics as are not fulled to any extent in the finishing. The latter class consists of the short-stapled fibres, which are **carded** and spun into **woolen** yarns to be used for weft and all classes of goods which

* This is also known as *tanners'* wool and *glovers'* wool.

† According to Höhnel, the diameter of sheep's wool varies from 10 to 100 μ (the expression $\mu = \frac{1}{1000}$ mm.); and according to Cramer, the thickness of the hairs from one and the same fleece may vary from 12 to 85 μ.

are fulled more or less in the finishing operations, where a felting together of the fibres is desired. On comparing worsted and woolen yarns, it will be noticed that the former are fairly even in diameter and the individual fibres lie more or less parallel to each other, whereas in woolen yarns the diameter is very uneven, and the fibres lie in all manner of directions.

The quality of wool obtained from sheep depends very largely on the breed, on climatic conditions, and nature of the pasturage on which the sheep feed. Australia appears to possess the climatic conditions best adapted for wool-growing.* With regard to the nature of the pasturage it has been found that grass from chalky soils gives rise to a coarse wool, whereas that from rich, loamy soils produces fine grades of wool.† As a rule, the sheep

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* Other conditions being equal, long droughty seasons in wool-growing districts will cause the fibre to be much shorter than otherwise.

† Utah wools, for instance, are harsh and stairy compared to Wyoming wools. This is due to the alkali in the soil in Utah and the dryness of the climate. The alkali in the soil and the effect it has upon the water which the sheep drink have a tendency to take the life out of the wool and weaken the staple. The more close and uniform the fibres lie, the better will be the combing qualities of the wool. The Utah wools in this respect are inferior to the Wyomings, Idahos, and Montanas, especially the wools grown in southern Utah. In northern Utah the wools are longer than in southern Utah, but there are very few Utahs either north or south which are fit for combing. The heaviest shrinkage wools generally come from eastern Oregon and Nevada. The degree of shrinkage depends to a considerable extent on the season in which the wools were grown. A wet season and long-continued rains will wash much dirt and dust out of the wools, thus leaving them lighter. The lightest shrinkage wools come from Virginia and Kentucky and the Blue Grass region, where medium wools are grown, where the sheep are cleaner, the range better, and the country hilly, and where comparatively little sand and dirt work their way into the fleece. The shrinkage of washed fleeces ranges from 55 to 35 per cent. Unwashed Indiana wools shrink 38 to 43 per cent. Missouris will shrink around 43 to 45 per cent.; Illinois, 45 to 47 per cent. California wools shrink 55 to 72 per cent., depending on the part from which they come. The heaviest shrinkage wools are in southern California, because of the presence of more sand and dirt, and inferiority of the range. Texas spring wools shrink anywhere from 64 to 72 per cent., and the fall wools 58 to 64 per cent. Territory wools shrink from 55 up to 73 per cent. Idahos on the medium order will not shrink over 55 per cent. Wyoming wools on the fine and fine medium order shrink 65 to 72 per cent. The Montanas shrink on the average 63 to 69 per cent. for fine and fine mediums, and 57 to 60 per cent. for mediums. The shrinkage on Arizona wools will range from 66 to 73 per cent., but they will spin to finer counts than the Utah wools, and will scour

which yield the best qualities of wool give the poorest quality of mutton.

Unhealthy conditions of the sheep almost always influence the fibre during that period of its growth. If the sheep, for example, is suffering from indigestion, cold, lack of proper nourishment, etc., the fleece during that time will develop tender fibres; when the sheep regains its normal condition of health, the fibre becomes strong again. Thus the fleece may have tender strata through it which will considerably affect the fibre and its uses. These tender spots, of course, render the wool unfit for combing purposes, and it must go into the "clothing" class, and will consequently sell for less money, other things being equal. It is no great injury to the wool, however, aside from spoiling it for combing, as the wool, after it has passed the tender spot, grows fully as well as before the sheep was ill. When sheep have been afflicted with scab, the latter shows itself in tender wool at the bottom of the fibre. The scab leaves a pus-like substance which adheres to the bottom of the fibres and dries there. Vermin on sheep have an influence on the wool; these creatures leave discolorations on the fibre which cannot be removed by scouring. The wool, being "off color," does not sell as well, and, moreover, the fibre is liable to be tender.

As to the amount of wool to be obtained from each sheep, it may be said that the average yield is from 4 to 15 lbs., though in some South American varieties the fleece may weigh as high as 30 to 40 lbs. With respect to the variation in fibres derived from different kinds of sheep, Bowman gives the following classification:

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out very white. In this latter respect the Wyoming wools are superior to any other grown west of the Mississippi River. The shortest wools grown in America are from California and Texas; they are used principally for felts and hats, though they can also be mixed in certain proportions with clothing wool. As the Territory wools are grown mostly in dry climates, they will gain somewhat in weight on being shipped to the Atlantic seaboard and stored for a few months. Utah wools will gain about 1 per cent., Montana wools about ¾ per cent., and Wyoming wools about 1 per cent. The wools from Ohio and other eastern States will not gain anything; in fact, will sometimes show a slight shrinkage. (*American Wool and Cotton Reporter.*)

(1) Those sheep the fibres of whose wool most nearly approach to a true hair, the epidermal scales being most horny and attached most firmly to the cortical structure. This class includes all the lustrous varieties of wool, besides alpaca and mohair.

(2) Those where the epidermal scales, though more numerous than in the first class, are less horny in structure and less adherent to the cortical substance of the fibre. This class includes most of the middle-wooled sheep and half-breeds.

(3) Those where the characteristics of true wool are most highly developed, such as suppleness of fibre and fineness of texture, the epidermal scales being attached to the cortical substance through the smallest part of their length. This class includes all the finest grades of sheep, such as the merino and crosses with it.

CHAPTER III.

THE CHEMICAL NATURE AND PROPERTIES OF WOOL AND HAIR FIBRES.

1. Chemical Constitution.—In its chemical constitution wool is closely allied to hair, horn, feathers, and other epidermal tissues. A distinction must be made between the fibre proper and the raw fibre as it comes from the fleece. In the latter condition it contains a large amount of dirt, grease, and dried-up sweat which have first to be removed by the scouring process before the pure fibre is obtained. Reserving these impurities for a further discussion which does not concern us at this point, and discussing only the fibre itself, it has been found to consist of five chemical elements; namely, carbon, hydrogen, oxygen, nitrogen, and sulphur. Nitrogen is an ingredient common to both wool and silk, but sulphur is distinctly characteristic of wool and hair fibres. To show the average amount of pure fibre to be obtained from raw fleece wool, the following analysis by Chevreul of a merino wool is given:

	Per Cent.
Earthy matter deposited by washing the wool in water.	26.06
Suint or yolk soluble in cold distilled water.	32.74
Neutral fats soluble in ether.	8.57
Earthy matters adhering to the fat.	1.40
Wool fibre.	31.23
	100.00

These figures are based on wool dried at 100° C.; if corrected for air-dry wool containing 14 per cent. of moisture, this would give only about 27.5 per cent. of pure fibre. Of course, the

amount of fibre will vary considerably in different qualities and samples of wools, but this figure may be taken as a fair average.

The presence of **nitrogen** in wool is readily made evident by simply burning a small sample of the fibre, when the characteristic empyreumatic odor of nitrogenous animal matter will be observed. By heating wool in a small combustion test-tube it will be noticed that ammonia is among the gaseous products evolved, and can be tested for in the usual manner. The presence of **sulphur** in wool can be shown by dissolving a sample of the fibre in a solution of sodium plumbite (obtained by dissolving lead oxide in sodium hydrate), when a brown coloration will be observed, due to the formation of lead sulphide. On adding hydrochloric acid to the solution and heating, the odor of sulphuretted hydrogen will be distinctly noticed. The application of this test to show the presence of sulphur in wool is sufficient to discriminate chemically between that fibre and those consisting of silk or cotton, and also to detect wool in admixture with other fibres. The older methods of hair-dyeing were based on this same reaction, solutions of soluble lead salts, such as sugar of lead, being applied to the hair, with the result that lead sulphide would be formed and cause a dark brown coloration. The use of such preparations, however, is dangerous, as they are liable to cause lead-poisoning.

The presence of sulphur in wool may at times be the cause of certain defects in the dyeing process. In neutral or alkaline baths, if lead is present, the color obtained on the fibre will be more or less affected by the lead sulphide formed on the wool, and serious stains may be the result. The presence of sulphuric acid, however, prevents this, and no staining of the fibre takes place. Stains are sometimes produced when wool is mordanted with stannous chloride, as in the dyeing of cochineal scarlets, due to the formation of stannous sulphide. Occasionally woolen printed goods exhibit brownish stains on the white or light-colored portions after being steamed. These may be due to slight traces of copper or lead being deposited on the cloth during its manipulation and passage through the machines, and these metals when the wool is steamed form dark colored sulphides which cause

the stains. By locally applying a weak solution of hydrogen peroxide such discolorations may be removed without injury to the printed color.

Chevreul recognized the fact that in certain dyeing operations it was necessary to remove the sulphur from wool as far as possible in order to obtain the best results. He accomplished this by steeping the wool in milk of lime and afterwards in a weak bath of hydrochloric acid, and finally washing.

The amount of sulphur existing in wool does not appear to be a very constant factor, but varies in different samples of wool from 0.8 to 4 per cent.* The manner in which the sulphur exists in the molecular structure of the fibre is by no means clear, as the majority of it is readily removed without any apparent structural modification of the fibre itself. According to Chevreul the amount of sulphur in wool was reduced to 0.46 per cent. by several treatments with lime-water. Treatment with a concentrated solution of caustic soda in such a manner as not to disintegrate the fibre (see p. 46) will remove as much as 84.5 per cent. of the sulphur originally present in the wool. On a sample of wool containing 3.42 per cent. of sulphur, treatment in this manner left only 0.53 per cent. of sulphur in the fibre. This would appear to indicate that the sulphur is not a structural constituent of the wool fibre.† The fact, however, that the sulphur present is not all removed by even such severe treatment as described would also serve to indicate that this element may exist in wool in two forms, the one an ultimate constituent of the fibre, and the other, and major part, as a more loosely combined compound. The fact that the amount of sulphur naturally present in wool is

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* Wool is similar to other albuminoids in that it contains a relatively small though a widely fluctuating amount of sulphur. The following sulphur compounds have been isolated from the decomposition products of the albuminoids: Cystin, cystein, thiolactic acid, thioglycollic acid, ethyl sulphide, ethyl mercaptan, sulphuretted hydrogen, and diethyl-thetin.

† The presence of sulphuric or sulphurous acids has formerly never been observed in the decomposition products of albuminoids and this led to the opinion that the albumin molecule did not contain sulphur in combination with oxygen. Raikow (*Chem. Zeit.*, 1905, page 900), however, finds that when purified, unbleached wool is treated with phosphoric acid considerable quantities of sulphurous acid are evolved.

by no means constant would also tend to support this view; as would also the fact that the major portion of the sulphur is so readily spilt off to form metallic sulphides. On dissolving wool in boiling caustic soda, it does not appear that all of the sulphur is converted into sodium sulphide, as only about 80 per cent. of it can be obtained as hydrogen sulphide when the caustic soda solution is treated with acid. Probably the remainder of the sulphur exists in the wool as a sulphonic acid, or some compound of a similar nature.

In its chemical nature wool appears to be a *proteoid*, known as **keratin**. As its constituents are not rigidly constant in their proportions, we cannot assign to wool a definite chemical formula.* On an average, its composition may be taken as follows:

Carbon	50
Hydrogen	7
Oxygen	26–22
Nitrogen	15–17
Sulphur	2– 4

* Keratin, free from ash, water, and melanin, on hydrolysis gave the following amounts of monamino-acids:

	Keratin from Horse-hair, Per Cent.	Keratin from Goose-feathers, Per Cent.
Glycin	4.7	2.6
Alanin	1.5	1.8
Amino-valeric acid	0.9	0.5
Leucin	7.1	8.0
Pyrolidin-2-carboxylic acid	3.4	3.5
Aspartic acid	0.3	1.1
Glutamic acid	3.7	2.3
Tyrosin	3.2	3.6
Serin	0.6	0.4

(Abderhalden, *Zeit. physiol. Chem.*, vol. 46, p. 31.)

According to the tables of Cohnheim, the percentages of known constituents in the keratin from hair are as follows:

	Per Cent.
Leucin	14
Glutaminic acid	12
Aspartic acid	not determined
Cystin	13.92
Tyrosin	3
Ammonia	large amount

Bowman gives the following analyses of four different grades of English wool:

Constituent.	Lincoln Wool.	Irish Wool.	Northumberland Wool.	Southdown Wool.
Carbon.............	52.0	49.8	50.8	51.3
Hydrogen.	6.9	7.2	7.2	6.9
Nitrogen.	18.1	19.1	18.5	17.8
Oxygen.	20.3	19.9	21.2	20.2
Sulphur.	2.5	3.0	2.3	3.8
Loss.................................	0.2	1.0	———	———

These analyses were made of wool which had been purified by extraction with water, alcohol, and ether.

The continued action of boiling water appears to decompose the wool fibre to a certain extent, as both ammonia and hydrogen sulphide may be detected in the gases evolved.*

By heating wool to a temperature of 130° C. with water under pressure, the fibre appears to become completely disorganized, and on drying may be rubbed into a fine powder. At higher temperature the fibre is completely dissolved. Based on this fact, Knecht has proposed a method for the carbonization of wool in mixed woolen and silk goods, for the purpose of recovering the silk, as the latter is not materially affected by this treatment.† The wool fibre as a whole does not appear to be a homogeneous chemical compound; instead of being a simple molecular body to which a definite formula might be given, it is doubtless composed of several chemically distinct substances. This is evidenced by the fact that the proximate constituents of wool are by no means constant in their amount; furthermore, certain of its constituents are in part removed by simply boiling the fibre in water without a structural disorganization taking place. The sulphur content is especially liable to fluctuation, and is the most

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* The soluble decomposition products of wool produced by boiling with water show all the characteristic properties of the peptones. Suida suggests that this action of boiling water on wool may account for the lack of fastness to rubbing often noticed with basic colors on wool.

† This method, though theoretically possible, does not have any practical value.

readily removed of the chemical elements of which the fibre is composed; in fact, so easily is some of the sulphur removed as such by various solvents, that it would seem to indicate that this constituent existed in wool either in the free condition or in a compound of exceedingly unstable character.

Schuetzenberger, by decomposing pure wool fibre by heating with a solution of barium hydrate at 170° C., obtained the following decomposition products:

	Per Cent.
Nitrogen (evolved as ammonia)	5.25
Carbonic acid (separated as barium carbonate)	4.27
Oxalic acid (separated as barium oxalate)	5.72
Acetic acid (by distillation and titration)	3.20
Pyrrol and volatile products	1 to 1.50

Proximate composition of fixed residue, containing leu-cin, tyrosin, and other volatile products	C	47.85
	H	7.69
	N	12.63
	O	31.83

Williams has shown that by distilling wool with strong caustic potash a large amount of ammonia was obtained in the distillate, together with butylamin and amylamin. Dry distillation of wool yields an oil of a very disagreeable odor, probably consisting of various sulphuretted bases; also a considerable amount of pyrrol and hydrogen sulphide gas, together with a small amount of carbon disulphide, and traces of various oily bases.

The fatty and mineral matters present on the raw wool fibre consist on the one hand of **wool grease** derived from the fatty glands surrounding the hair-follicle in the skin, and on the other hand of **dried-up perspiration** from the sudorific glands in the skin. The wool grease is mostly to be found as the external coating on the fibre * which serves to protect it from mechanical injury and felting while in the growing fleece.† There is also a

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* The statement made in some text-books that raw wool when left in the greasy condition is not attacked by moths is erroneous. The personal experience of the author has proved that raw wool is as liable to the depredations of insects as washed and scoured wool.

† Cotted fleeces are those in which the fibres have grown in and amongst each other on the sheep's body, so that they form a more or less perfect mat of wool. These mats are hard or soft according to the extent to which the matting process has been carried on. Cotted fleeces occur mostly in sheep which have been housed; they are seldom found in the territories where the sheep run on the range

small amount of oily matter contained in the medullary intercellular structure of the fibre which appears to have the function of acting as a lubricant for the inner portion of the fibre, thus preserving its pliability and elasticity. Wool grease does not appear to be a simple compound, but evidently consists of several oils and wax-like compounds.

Its chief constituent is **cholesterol,** which appears to be one of the higher monatomic alcohols, and is not a glyceride. Analysis shows it to have the formula $C_{26}H_{43}OH$. It is a solid wax-like substance which very readily emulsifies in water. Associated with cholesterol there is also an isomeric body called *isocholesterol*. Besides these solid waxes, wool grease also contains two fats which have been studied by Chevreul to some extent. These are described as follows:

(*a*) *Stearerin*, a neutral solid fat, melting at 60° C.; contains neither nitrogen nor sulphur; does not emulsify with boiling water, but emulsifies without saponification when boiled with caustic potash and water; it is soluble in 1000 parts of alcohol at 15.5° C.

(*b*) *Elairerin*, a neutral fat melting at 15.5° C.; also free from nitrogen and sulphur; it emulsifies with boiling water, and is saponified with caustic potash; it is soluble in 143 parts of alcohol at 15.5° C.

The dried-up perspiration adhering to the raw-wool fibre is also called **suint**. It consists principally of the potash salts of various fatty acids, and it is soluble in water, wherein it differs from wool grease. On extraction with water, suint will yield a dry residue of about 140 to 180 lbs. for 1000 lbs. of raw wool. This on ignition will give 70 to 90 lbs. of potassium carbonate and 5 to 6 lbs. of potassium sulphate and chloride, so that the

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and are more exposed and hardy. Cotted fleeces indicate a low degree of vitality, and many are to be found in fleece wool from States east of the Mississippi River, They may be caused by sickness or a low state of the blood, or they may be found in an old sheep which is giving out or is run down, which contributes to the frowsy condition of the wool. Cotted fleeces are unfit for combing purposes, as they have to be torn apart, and frequently they are so dense and hard that the fibres can only be pulled apart by the use of special machinery. Badly cotted fleeces are used frequently for braid purposes.

amount of potash salts to be derived from raw unwashed wool
may be taken to be about 10 per cent. on the weight of the wool.

Besides the mineral matter existing in the soluble suint, there
is also a small amount of mineral matter which appears to form an
essential constituent of the fibre itself.*   It is left as an ash when
wool is ignited, and amounts on an average to about 1 per cent.,
the majority of which is soluble in water and consists of the alka-
line sulphates.   The following analysis by Bowman shows the
typical composition of the ash of Lincoln wool:

	Per Cent.
Potassium oxide	31.1
Sodium oxide	8.2
Calcium oxide	16.9
Aluminium oxide } Ferric oxide	12.3
Silica	5.8
Sulphuric anhydride	20.5
Carbonic acid	4.2
Phosphoric acid	trace
Chlorin	trace

Sheep's wool is nearly always white in color, though sometimes
it may occur in the natural colors of gray, brown, or black.   The
coloring-matter in wool appears to withstand the action of alkalies

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* Arsenic appears to be present in nearly all samples of wool, even in the
natural state.   The arsenic is generally derived from the dips to which the sheep
are subjected even the wool from a lamb whose mother has been dipped a con-
siderable time before the lamb's birth will show distinct traces of arsenic.   Thorpe
gives the following figures for the amounts of arsenic in woolen materials:

	Arsenious Oxide, Mgms. per Gram of Material.
Flannel from natural wool	0.005–0.009
White Berlin wool	0.037
Cream flannel	0.004
Welsh flannel	0.015
Vest wool (undyed)	0.011
Linen (white)	free
Silk (undyed)	0.001
Wool from lamb (mother treated with arsenical dip)	0.0005
Wool from lamb (mother dipped shortly before birth of the lamb)	0.019
Wool from ewe (treated with carbolic dip 15 months previously)	0.047

and acids, though it is not especially permanent toward light. It appears to be distributed in the fibre in quite a different manner from that of the artificially applied dyes. The natural coloring-matter appears to be contained particularly in the cells of the cortical layer and the marrow in a granular form, and to occur to a greater extent in the medullary than in the cortical cells. In fibres which are only slightly colored the walls of the cells are almost colorless; though when the fibre becomes very strongly colored the cell-walls also appear to be impregnated with the coloring-matter. In wools which have been dyed, however, the cell-walls are nearly always uniformly colored, in consequence of which the medulla of the fibre becomes less pronounced; whereas, with naturally colored wools, the medulla is usually rendered more distinct through the deposit of coloring-matter.

2. Chemical Reactions.—In its chemical reactions wool appears to exhibit the characteristics both of an acid * and a base, and no doubt it contains an amido acid in its composition. The presence of an amido group is evidenced by the formation of ammonia as one of the decomposition products of wool, also by the strong affinity of wool for the acid dyestuffs, or even of its ability to combine with acids in general.

Schuetzenberger has shown that the products of the hydrolysis of wool by baryta-water are analogous to those of albuminoids containing imido groups; the experiments of Prud'homme and Flick also indicate the presence of imido rather than amido groups in wool. The fact that wool absorbs nitrous acid, and combines with phenols, which is supposed to indicate the presence of amido groups, may be explained by the formation of nitrosamines with the imido groups, which would also yield colored derivatives with phenols.

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* The acid nature of wool accounts for the possibility of the formation of compounds of the fibre with various metallic salts, alkalies, and metallic oxides, and therefore for the difference in behavior in dyeing between wools which have been scoured with alkaline carbonates or treated with metallic salts or hard water and wool which has not had its acid groups saturated in this way. It also accounts for the fact that different wools require the addition of different amounts of acid to the dye-bath to give the same effect. (See experiments of Gelmo and Suida, *Ber. Akad. Wissenschaften*, May, 1905.)

The coefficient of acidity, which is a figure meaning the number of milligrams of caustic potash neutralized by one gram of substance, has been determined for wool, together with a number of other albuminoids, as follows:

Wool.	57.0	Albumin.	20.9
Silk.	143.0	Gelatin.	28.4
	Globulin.	101.5	

Although the amount of acid absorbed and neutralized by wool may be thus quantitatively determined, the amount of alkali absorbed cannot be so obtained, as wool, though it absorbs alkalies, does not neutralize them.*

By treatment with concentrated solutions of caustic soda (80° Tw.) wool absorbs about 50 per cent. of its weight of sodium hydrate from solution. Nor can this alkali be totally removed from the wool by subsequent washing with water alone, but requires a treatment with acid for complete neutralization. Wool so treated exhibits a lessened affinity for basic dyes, showing a probable neutralization to a greater or lesser extent of its acid component.

The amido acid of keratin has received the name of **lanuginic acid,** and has been prepared by dissolving purified wool in a strong solution of barium hydrate, precipitating the barium by means of carbon dioxide, and after filtering, treating the liquid with lead acetate, whereby the lead salt is obtained. This is decomposed by means of hydrogen sulphide, and the lanuginic acid obtained, after evaporation, as a dirty-yellow substance. Its solution in water yields colored lakes with the acid and basic dyestuffs, and also with the various mordants.

According to Knecht, lanuginic acid possesses the following properties: It is soluble in water, sparingly so in alcohol, and insoluble in ether. Its aqueous solution yields highly colored precipitates with the acid and basic dyestuffs; tannic acid and

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* Wool which has been treated with a dilute solution of caustic alkali apparently shows no difference from untreated wool in its dyeing properties with respect to acid and basic dyes. That alkali has been absorbed by the wool, however, is shown by the fact that it has an increased attraction for such dyes as Benzopurpurin and Bordeaux, which only dye wool from a slightly alkaline bath.

bichromate of potash also give precipitates. The following mordants in the presence of sodium acetate also give precipitates: alum, stannous chloride, copper sulphate, ferric chloride, ferrous sulphate, chrome alum, silver nitrate, and platinum chloride. Lanuginic acid exhibits all the properties of a proteoid, and may therefore be classed among the albuminoids; it is soluble in water at all temperatures, and its solution is not coagulated. With Millon's reagent and with the double compound of phosphoric and tungstic acids, it shows the characteristic albuminoid reactions. Knecht recommends the use of a solution of wool in barium hydrate for the purpose of animalizing vegetable f.bres. Cotton so treated is capable of being dyed with acid and basic dyestuffs.

When heated to 100° C., lanuginic acid becomes soft and plastic, and the majority of its colored lakes also melt at this temperature. Knecht gives the following analysis of lanuginic acid:

	Per Cent
Carbon	41.61
Hydrogen	7.31
Nitrogen	10.26
Sulphur	3.35
Oxygen	31.44
	93.97

Though lanuginic acid contains a notable amount of sulphur in its composition, it is not blackened by treatment with sodium plumbite.

When treated with **dilute acids**, the wool fibre does not appear to undergo any appreciable change; although, from the fact that acids are very readily absorbed by wool and very tenaciously held by it, there is reason to believe that some chemical combination takes place between the fibre and the acid. It can be shown, for example, that if wool be treated with dilute **sulphuric acid**,* all of

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* Wool that has been treated with warm dilute solutions of sulphuric acid not only shows an increased affinity for acid colors, but also a much decreased affinity for basic colors. Treatment of wool with cold aqueous or alcoholic solutions of sulphuric acid, however, followed by washing with cold water, appears to diminish the affinity of the fibre for acid colors, from which it is concluded

the acid cannot again be extracted by boiling in water until the wash-waters are perfectly neutral; and wool thus prepared has the power of combining with the various acid colors without the necessity of adding any acid to the dye-bath. It is also true that if wool which has been treated with sulphuric acid is boiled in water, ammonium sulphate is to be found in the solution, showing that some chemical action has probably taken place between the acid and some basic constituent of the wool fibre. **Hydrochloric acid** acts much in the same manner as sulphuric acid, although the amount permanently absorbed by the fibre is quite small, most of the acid being removed by boiling water. **Chromic acid** is also absorbed in like manner, and no doubt the usefulness of bichromates as mordants for wool depends somewhat on the chemical combination between the fibre and the chromic acid. With **nitric acid** wool behaves somewhat differently, for unless the acid be very dilute and the temperature low, the fibre will assume a yellow color, which is probably due to the formation of xanthoproteic acid. Formerly this yellow color was supposed to be due to the formation of picric acid, but this view is erroneous. Nitric acid has a similar effect on the skin, the yellow stains which it produces being a subject of common experience. If the strength of the acid is below 4° Tw., the yellow coloration on wool is not very marked, and in this manner nitric acid has been largely employed as a stripping agent, especially for shoddies.

Richards has shown that by the action of **nitrous acid**, wool is diazotized in a manner similar to an amido compound, and may be developed subsequently in an alkaline solution of a phenol, giving rise to quite a variety of shades. When wool is treated in the dark with an acid solution of sodium nitrite (6 per cent.) it quickly acquires a pale-yellow color, rapidly changing on exposure to light. Wool prepared in this manner is turned brown by

that the acid is fixed in a somewhat different way than when the wool is heated with the acid solution. Acidified wool also shows an increased power of dyeing alizarin colors direct. Other acids have about the same effect on wool as sulphuric acid, only in the case of acetic acid it is necessary to add the acid directly to the dye-bath in order to hinder the fixation of basic colors or increase the absorption of acid colors. (See Gelmo and Suida, *Ber. Akad. Wissenschaften*, May, 1905.)

boiling water, and caustic soda effects the same change, the color becoming yellow again on treatment with acids. Stannous chloride in a warm solution discharges the brown color. Diazotized wool appears to have an increased attraction for basic dyes and a lessened affinity for the acid dyes. Exposure to light bleaches diazotized wool, which is then turned orange by alkalies, and not brown. The following colors may be obtained by treating diazotized wool with various phenols in alkaline solution:

Phenol.	Color.	Reaction with H_2SO_4.
Resorcin	Orange	Pale red
Orcin	Orange	Pale red
Pyrogallol	Yellowish brown	Orange
Phloroglucin	Bordeaux	No change
α-Naphthol	Red	Black
β-Naphthol	Red	Pale red

When dyed in connection with metallic mordants, these phenol colors are fast to light, fulling, acids, and boiling water. Tin mordants give yellow and orange shades, aluminium orange, iron dark browns and olive browns, chromium and copper garnet. Wool treated with nitrous acid acquires a harsh feel and is non-hygroscopic.

Its acid number is 169, and its iodin number 4.7, whereas untreated wool has the numbers 88 and 18.4 respectively. It also appears to contain less nitrogen than ordinary wool.*

Vignon † has experimented on the amount of heat disengaged by treating wool with different acids and alkalies, with the following results, using 100 grams of unbleached wool:

Reagent.	Calories Liberated.
Potassium hydrate (normal).	24.50
Sodium hydrate (normal).	24.30
Hydrochloric acid (normal).	20.05
Sulphuric acid (normal).	20.90

These figures are interesting in indicating the relative acidity and alkalinity of the wool fibre.

In common with most other organic substances, wool is

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* Lidow, *Chem. Centr.*, 1901, I, 703.
† *Compt. rend.*, 1890, No. 17.

totally destroyed by the action of **concentrated mineral acids.***

With **organic acids**, wool is usually reactive, readily absorbing oxalic, lactic, tartaric, acetic, etc., acids. **Tannic acid**, however, is an exception, and is not absorbed to any extent by the fibre. But if wool is treated in a boiling solution of tannic acid and the latter fixed in the fibre by a subsequent treatment in a solution of tartaric emetic (or other suitable metallic salt), it will be found that the fibre becomes altered in such manner that it no longer exhibits its normal affinity towards acid, substantive, and mordant dyes. Towards basic dyes, however, the affinity of the wool becomes considerably increased by reason of the presence of tannin.

Although so resistant to the action of acids, on the other hand, wool is quite sensitive to **alkalies**; so much so, in fact, that a five per cent. solution of caustic soda at a boiling temperature will completely dissolve wool in five minutes. From this fact it is easy to understand why soaps, and scouring and fulling agents in general, should be free from appreciable amounts of caustic alkalies. The weaker alkaline salts, such as the carbonates, soaps, etc., are not so destructive in their action, and when employed at moderate temperatures they are not regarded as deleterious, and are largely used in scouring and fulling. With respect to the amount of caustic alkali necessary to decompose wool, Knecht found that on boiling wool for three hours with three per cent. (on the weight of the wool) of caustic soda the fibre was not disintegrated, but on increasing the amount to six per cent., complete disintegration took place and the wool was almost entirely dissolved.

The action of concentrated solutions of caustic alkalies on wool is a rather peculiar one.† Solutions of caustic soda of a strength below 75° Tw. will rapidly disintegrate the fibre, but with solutions of 75°–100° Tw. the fibre is no longer disintegrated,

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* On treatment with cold concentrated sulphuric acid for a short time wool is not seriously disintegrated; the fibre, however, suffers a change in that it loses all affinity for acid dyes, while it strongly attracts basic dyes. (*Text. Rec.*, vol. 22, p. 229.)

† Kertesz, *Färber-Zeit.*, vol. 9, pp. 35–36; Buntrock, *ibid.*, vol. 9, pp. 69–71.

but, on the other hand, increases from 25 to 35 per cent. in tensile strength, becomes quite white in appearance, and acquires a high lustre and a silky scroop. The maximum effect is obtained by using a caustic soda solution of 80° Tw. and keeping the temperature below 20° C.* The duration of the treatment should not be more than five minutes. The addition of glycerol to the solution of caustic soda renders the action of the alkali more effective. Wool treated in this manner may be said to be "mercerized," though the action of the caustic soda in this case is not quite analogous to that in the mercerization of cotton. From the decrease in the density of the caustic soda solutions employed, it has been shown that the wool absorbs a considerable amount of sodium hydrate from solution. Whether this is held by the wool in true chemical combination has not been ascertained. The treated wool contains but a small amount of sulphur compared with that present in the original fibre (see page 35); analysis, in fact, shows that only about 15 per cent. of the original sulphur remains in the mercerized wool. The dyeing qualities of the latter are also different from the original fibre in that it absorbs more dyestuff from solution and hence yields heavier shades. Quantitative tests have shown that the increase in the absorption of dyestuffs is as follows:

Class of Dyestuffs.	Increase, Per Cent.
Basic.	12.5
Acid.	20.0
Substantive.	25.0
Mordant.	33.3

Mercerized wool also shows an increased absorption with respect to solutions of various metallic salts.

The exact nature of the action of caustic soda under the conditions given is rather difficult to satisfactorily explain. Through a microscopic examination of the treated fibres it appears that the individual scales on the surface of the wool are more or less fused together to a smooth surface, which would account for the great increase in lustre. The additional tensile strength is probably accounted for by the same fact, the closer adhesions of the

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* Matthews, *Jour. Soc. Chem. Ind.*, vol. 21, p. 685.

scales giving a greater rigidity to the fibre. The volatile alkalies, such as ammonia and ammonium carbonate, do not have any marked deleterious effect on wool, especially at low temperatures; hence these compounds form excellent scouring materials. The hydroxides of the alkaline earths, though less violent in their action than the fixed caustic alkalies, nevertheless decompose wool. Milk of lime, even in the cold, abstracts most of the sulphur, and also causes the fibre to become hard and brittle if the action is prolonged; the wool also loses its felting quality to a considerable extent. Barium hydroxide, as already noted, is used for the decomposition of wool in the preparation of lanuginic acid.

Towards other chemical reagents wool is much more reactive than cotton, and either absorbs from solution or chemically combines with many substances. The fibre is quite readily oxidized when treated with strong **oxidizing agents** such as potassium permanganate or bichromate, becoming greatly deteriorated in its qualities.

Towards **chlorin** wool acts in a peculiar manner; it is completely decomposed by moist chlorin gas, but in weak solutions it absorbs a considerable amount of chlorin and is strangely altered in its properties.* It becomes harsh,† has a high lustre, and acquires a silk-like feel or "scroop," at the same time losing its felting properties, though its attraction for coloring-matters in general is largely increased.‡

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* Bromin appears to have a similar action on wool. It is claimed to have the advantages over chlorin in that it does not turn the material yellow, and that in mixtures of dyed and undyed wool the former is not attacked. This latter statement is open to doubt.

† According to a recent German patent, the harshness of chlorinated wool may be considerably lessened by working the material first in a solution of a salt such as citrate of zinc or acetate of iron, or of sodium stannate or aluminate; this is followed by a second bath of very dilute alkali, after which the goods are exposed to the air. The author, however, has not been able to obtain any satisfactory results on testing this process.

‡ Chlorinated wool finds quite a number of applications in practice. The process is used, for instance, for the purpose of imparting a silk-like gloss to the fibre. Again, if yarns of chlorinated wool and ordinary wool are woven together in pattern, and the fabric afterwards fulled, since the chlorinated wool does not felt it will not shrink up like the remainder of the yarn, and in consequence the pattern will be brought out with very good effect; a great variety of novelties

With *neutral* **metallic salts** wool does not seem very reactive, as it does not absorb them appreciably from their solutions. With salts, however, which are *acid* in reaction and are capable of being easily dissociated, such as alum, ferrous sulphate, etc., the wool fibre possesses considerable attraction, especially when boiled in their solutions.*

With regard to **coloring-matters**, wool is the most reactive of all the textile fibres, combining directly with acid, basic, and most substantive dyestuffs, and yielding, as a rule, shades which are much faster than those obtained on other fibres.

There have been various opinions put forward as to the influence in dyeing of the active chemical groups in wool. If

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may be produced in this manner. Finally, the property of chlorinated wool to take up more dyestuff than ordinary wool, when dyed in the same bath, is also utilized; and fabrics with beautiful two-color effects may be easily obtained in this manner by weaving the chlorinated wool into designs with ordinary wool and afterwards dyeing with suitable coloring-matters.

The chlorination of the woolen yarn is carried out in practice as follows: The material is well freed from all greasy matters by a preliminary scouring; this must be very thorough, otherwise good results will not be obtained, as the yarn is liable to finish up very uneven. A steeping in hydrochloric acid next takes place; the solution should be cold and have a density of $1\frac{1}{2}°$ Tw. The wool should be left in this bath for twenty minutes. It is next passed into a solution of bleaching powder standing at $3°$ Tw. and worked for ten minutes, after which it is again treated with the solution of hydrochloric acid and washed thoroughly. It is said that sodium hypochlorite is better to use than chloride of lime, and sulphuric acid is preferable to hydrochloric, showing less tendency to turn the material yellow. The yellow color due to the chlorin may be removed by treatment with sulphurous acid.

* Schellens (*Arch. Pharm.*, 1905, p. 617) has furnished some interesting experiments showing the relative power of fixation of metallic salts possessed by various textile fibres. With solutions of ferric chloride, for instance, the following results were obtained:

	Solution No. 1, containing 1 Per Cent of Iron.	Solution No. 2, containing 0.1 Per Cent of Iron.
Cotton-wool	0.112	0.112
Filter-paper	0.23	0.123
Vegetable silk	1.01	0.56
Jute	0.56	0.44
Raw silk	0.67	0.67
Wool	0.84	0.36

The figures refer to the weight of iron fixed by 1 gram of the fibre from 50 cc. of the respective solutions.

the phenomena of dyeing were principally of a chemical nature we would expect this influence to be a considerable one. In the case of acid and basic dyes, we have to deal with bodies possessing definite chemical characteristics; that is to say, acid dyes are acid in nature, while basic dyes have basic properties. From the facts already put forward that wool consists principally of an amido-acid, and is therefore capable of exhibiting both acid and basic properties, it would be natural to expect that in dyeing with acid coloring-matters there would be (to some degree at least) the formation of a compound between the acid of the dye-stuff and the base of the wool; and likewise, in dyeing with basic coloring-matters the basic portion of the dyestuff would combine with the acid portion of the wool. That such a combination in reality does take can hardly be doubted, for many experimental facts have been adduced leading to such a conclusion. Aside from the fact that wool combines directly with acid and basic coloring-matters, it has also been shown * that when the active chemical groups in the fibre are neutralized by proper chemical treatment, the reactivity of wool towards acid and basic dyes respectively is much decreased. The acid nature of wool may be almost completely neutralized by acetylation with acetyl chloride,† and the resulting fibre shows but very slight reactivity towards basic dyes, and a correspondingly increased reactivity towards acid dyes.

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* Suida, *Färber-Zeit.*, 1905.

† Suida has found that when wool is heated with acetyl chloride at the temperature of the water-bath a copious evolution of hydrochloric acid takes place, indicating the formation of an acetyl compound. Wool which has been thus treated and freed from all excess of the reagent by alternate rinsing with alcohol and water is found to have lost to a great extent its affinity for the basic coloring-matters. Wool treated with acetic anhydride shows the same effect. Microscopical examination in both cases does not exhibit any structural modifications in the fibre. On heating wool which has been treated in this manner with a weak solution of ammonium carbonate (a reagent which is capable of saponifying acetyl compounds), the wool again regains its normal character with respect to its behavior towards basic dyestuffs. A change of the same character in wool is produced by heating the fibre on the water-bath with alcohol in the presence of a small amount of strong sulphuric acid. This treatment also appears to form an ester which is saponified by treatment afterwards with an alkali, so that the wool regains its original condition.

If wool is left in a warm place in a moist condition so that the fibre does not have free access to plenty of fresh air, it will soon develop a fungoid growth or **mildew** in spots. This causes the fibre to become tender and eventually rot. This fungoid growth will develop without any sizing ingredients or other foreign matter being present on the fibre. It rapidly attacks the scales on the surface of the fibre, and then eats into the inner substance of the wool. Under the microscope (see Fig. 16) this fungoid growth appears as two forms: (*a*) Small elliptical cells which adhere to the surface of the fibre and spread out from it; they seem to colonize especially at the joints of the scales; (*b*) a tree-like growth consisting of several cells joined together and branching off from one another; these grow over the fibre as a kind of filmy integument, and do not appear to corrode the wool

FIG. 16.—Wool Fibres Attacked by Mildew. ($\times$ 300.)

a, fungus growing in jointed cells, tree-like; *b*, fungus growing in isolated cells. (Micrograph by author.)

as rapidly as the first kind of cells. Mildew is especially apt to develop on woolen material which contains a small amount of alkali, the alkaline reaction probably being favorable to the growth of the fungus.*

3. Microchemical Reactions.—The chemical reactions of the wool fibre under the microscope are not as characteristic as its physical structure. With concentrated hydrochloric or sulphuric acid the fibre gradually dissolves with a red coloration; with nitric acid it dissolves with much difficulty and with a yellow color; ammoniacal copper oxide causes the fibre to distend considerably with gradual disintegration, bringing the scale markings into prominence; solutions of copper or ferric sulphate stain the fibre black.

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* Hence the tendency of wool dyed in the indigo-vat to develop mildew stains.

4. Hygroscopic Quality.—Wool is more hygroscopic than any other fibre, but the amount of moisture it will contain will vary considerably according to the humidity and temperature of the surrounding atmosphere. Under average conditions, however, it will contain from 12 to 14 per cent. of absorbed moisture. The hygroscopic quality of wool is a subject of considerable importance in the commercial handling of this fibre, for the weight of any given lot of wool will vary within large limits in accordance with climatic conditions; that is to say, the shipment of wool from one locality to another of different humidity and temperature will cause a loss or gain in the apparent weight of the material. So important a factor has this become in the commercial relations between wool-dealers, that conditioning houses for wool have been established in many European centres for the purpose of carefully ascertaining the actual amount of fibre and moisture present in any given lot of wool, the true weight being based on a certain standard percentage of moisture, or so-called "regain." This percentage varies somewhat with the character of the material and also the conditioning house, ranging from 16 to 19 per cent. The hygroscopic quality of wool also has an important bearing on the spinning and finishing processes for this fibre, it being necessary to maintain a definite and uniform condition of moisture in order that the best results be obtained in the spinning of yarns and the finishing of the woven fabric. The wool fibre also appears to possess a certain amount of *water of hydration*, which is no doubt chemically combined in some manner with the fibre itself; for it has been observed that wool heated above 100° C. becomes chemically altered through a loss of water at that temperature. This will no doubt explain the fact that air-dried wool is superior in quality to that dried by means of artificial heat, which usually signifies a rather elevated temperature. According to Persoz, the destructive action of high temperatures on the wool fibre may be prevented by saturating the material with a 10 per cent. solution of glycerol, after which treatment the wool may be exposed to a temperature of 140° C. without being affected. The explanation of this action is no doubt to be found in the fact that glycerol holds water with considerable energy, and even

at these elevated temperatures all of the moisture originally present in the wool is not driven out of the fibre. In order to economize time, it is sometimes necessary to dry wool rather quickly by the use of suitable machinery and high temperatures. Where a proper regulation of the temperature is possible, the wet wool may be subjected to quite a high degree of heat without injury, for the fibre itself does not become heated up, due to the rapid evaporation of the moisture. As the fibre becomes drier, however, it is important that the temperature fall, so that at the end of the operation, when the wool has become dried to its normal content of moisture, the temperature should be that of the atmosphere.

Too much importance cannot be attached to the proper drying of wool in all of its stages of manufacture, either in scouring, dyeing, washing, or finishing. If wool is overdried, that is, if the moisture in it is reduced to an amount much less than that which it would normally contain, inferior goods will always be the result, for the intrinsic good qualities of the fibre become greatly depreciated every time such a mistake is committed.

The following table shows the percentage of moisture in air-dried wool and when exposed to an atmosphere saturated with moisture, as compared with the same values for other fibres:

Fibre.	Air-dry.	Saturated.	Fibre.	Air-dry.	Saturated.
Wool.	8–14	30	Manila hemp. . . .	8–12	40
Silk.	10–12	30	Jute	6	23
Cotton.	6–8	21	Flax.	5–8	13
Ramie.	6–8	18			

5. Conditioning of Wool.—In speaking of the hygroscopic quality of wool, it was mentioned that this fibre was capable of absorbing a considerable amount of moisture, and that this amount varied within rather large limits, depending upon the conditions of temperature and humidity of the air to which it may be exposed. It may be readily understood from these facts that in the buying and selling of wool and woolen goods upon a basis of weight, the question as to how much moisture is present becomes of great practical importance in determining the money value of the

operation. In England and on the continent of Europe, this fact has been recognized for some time, and there have been established at the various European wool-centres official laboratories where the percentage of moisture in raw wool or in manufactured woolen material is carefully ascertained, and the sales are based on the actual amount of normal wool fibre contained in the lot examined. These official laboratories * are called "conditioning houses," and the process of determining the amount of moisture in the wool is termed "conditioning." In the conditioning of wool the operation is carried out as follows: Representative samples are taken from the lot under examination; these are mixed together, and three test samples of $\frac{1}{2}$ to 1 lb. each are taken. The test sample, after being carefully weighed, is placed in the conditioning apparatus and dried to constant weight at a temperature of 105°–110° C. (220° F.). This weight represents the amount of dry wool fibre present in the sample, the loss in weight represents the amount of moisture the wool contained. The amount of normal wool is obtained by adding to the dry weight of the wool the amount of moisture supposed to be present in the air-dried material under normal conditions of humidity and temperature. The added amount is termed "regain," and is officially fixed by the conditioning house. This permissible percentage of regain varies with the form of the manufactured wool; the conditioning house at Bradford,† England, for instance, has established the following figures:

	Per Cent.
Wools.	16
Tops combed with oil.	19
Tops combed without oil.	$18\frac{1}{4}$
Noils.	14
Worsted yarns.	$18\frac{1}{4}$

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* The first official conditioning house was established at Lyons in 1805 for the conditioning of silk.

† The system of conditioning adopted at Bradford is as follows: The weights of the packages and conditions are taken by three persons independently on sensitive scales which are adjusted weekly. These scales have a weighing capacity from one-half pound to ten tons. In making the tests for moisture, the samples are carefully selected from various parts of the packages. The amount of the material taken for this purpose is for wools, noils, and wastes, about two pounds from each package; for tops, three balls; for yarns in hank, about four pounds

The conditioning house at Roubaix, on the Continent, allows following percentages for regain on woolen materials:*

	Per Cent
Wools	$14\frac{1}{4}$
Tops	$18\frac{1}{4}$
Woolen yarns	17

The percentage of regain allowed at Bradford is considerably higher than would be indicated by the amount of moisture in woolen materials in the vicinity of Philadelphia. The author has found from many conditioning tests at the Philadelphia Textile School that woolen yarns will average about 10 per cent. of moisture, worsted tops (in the oil) and loose wool about 12 per cent., and woven fabrics of wool about 8 to 9 per cent. This would correspond to a regain on the dry weight as follows:

	Per Cent.
Woolen yarns	11.1
Worsted tops and loose wool	13.6
Woolen cloth	9.9

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in 1200 pounds; for yarns on bobbins or tubes, twenty to forty bobbins or tubes, and for yarns on cones, cheeses, etc., five to fifteen pounds.

The standard regains and allowances are as follows:

Wools and waste, for moisture, a regain of 16 per cent., equal to 2 ozs. $3\frac{1}{4}$ drs. per lb.

Tops combed with oil, for moisture, a regain of 19 per cent., equal to 2 ozs. 9 drs. per lb.

Tops combed without oil, for moisture, a regain of $18\frac{1}{4}$ per cent., equal to 2 ozs. $7\frac{1}{2}$ drs. per lb.

Ordinary noils, for moisture, a regain of 14 per cent., equal to 1 oz. $15\frac{1}{2}$ drs. per lb. Clean noils, a regain of 16 per cent., equal to 2 oz. $3\frac{1}{4}$ drs. per lb.

Yarns, worsted, for moisture, a regain of $18\frac{1}{4}$ per cent., equal to 2 ozs. $7\frac{1}{2}$ drs. per lb.

Yarns, cotton, for moisture, a regain of $8\frac{1}{2}$ per cent., equal to 1 oz. 4 drs. per lb.

Yarns, silk, for moisture, a regain of 11 per cent., equal to 1 oz. $9\frac{1}{4}$ drs. per lb.

Cloths, worsted and woolen, a regain of 16 per cent., equal to 2 ozs. $3\frac{1}{4}$ drs. per lb.

* The International Congress at Turin (1875) fixed the amount of "regain" for different textile fibres as follows:

Silk	11	per cent.
Wool (tops)	$18\frac{1}{4}$	" "
Wool (yarn)	17	" "
Cotton	$8\frac{1}{2}$	" "
Linen	12	" "
Hemp	12	" "
Jute	$13\frac{3}{4}$	" "
New Zealand hemp	$13\frac{3}{4}$	" "

In order to give fair regains for commercial purposes, the author would recommend for woolen yarns a regain of 11 per cent., for tops and roving and loose wool, 15 per cent., and for wool cloth 11 per cent. For silk the regain allowed should be 11 per cent., and for cotton and vegetable fibres in general the regain should be 7 per cent.

In the United States Government specifications for army blankets, etc., of wool, a regain of 11 per cent. is allowed.

The method of calculating the amount of normal wool may be illustrated by the following example: A lot of 1000 lbs. of loose wool was submitted for conditioning; ten samples of 1 lb. each were taken from different parts of the lot; these were mixed together and three samples of 250 grams each were taken for testing.   On drying to constant weight the three samples lost, respectively, (1) 12.25 per cent., (2) 12.30 per cent., (3) 12.22 per cent., making the loss 12.26 per cent.   Hence in the entire lot of 1000 lbs. of wool there were 122.6 lbs. of moisture or 1000 − 122.6 = 877.4 lbs. of dry wool.   The permissible amount of regain in this case was 15 per cent.; hence the amount of normal wool would be $\left(877.4 \times \dfrac{15}{100}\right) + 877.4 = 1009$ lbs. instead of 1000 lbs.

The apparatus employed for the conditioning test is usually one of such a construction as to be especially adapted for the purpose.   The form may differ somewhat in details with different makers, but a typical conditioning oven may be described as follows:

The apparatus consists of an upright oven heated by a flame placed in the lower chamber.   An even temperature is maintained by so conducting the currents of heated air that they pass completely around the inner chamber or oven containing the sample to be tested (see Fig. 17).   A thermometer projecting into the oven from above is employed for indicating the temperature, and this may be maintained at the desired point by a proper regulation of the supply of heat.   The material to be conditioned, in whatever form (as loose wool, yarn, etc.), is placed in a wire basket suspended from one arm of a balance fixed outside and above the

oven; the weight of the basket and its contents is counterpoised
by placing definite weights on a scale-pan suspended from the
other arm of the balance. As the material diminishes in weight
through the volatilization of its moisture, the loss is noticed from
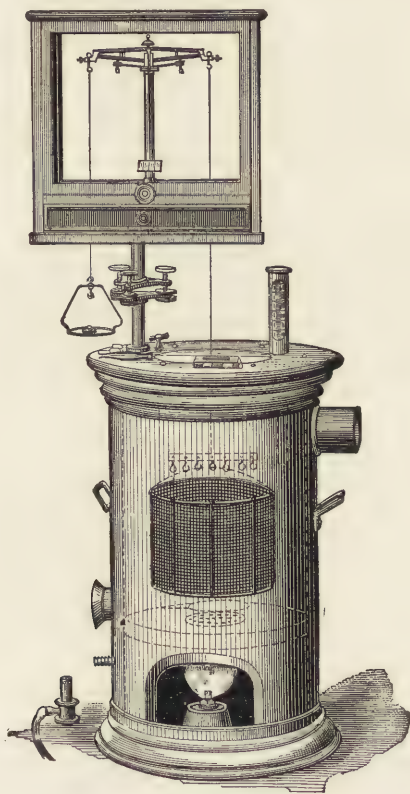time to time by removing the necessary weights from the scale-pan

FIG. 17.—Conditio ing Apparatus.

in order to restore the equilibrium of the balance. When the
weight becomes constant after heating at 110° C., the total loss is
recorded, and this figure represents the amount of moisture
which was originally present in the material tested. The balance
is usually enclosed in a suitable case in order to protect it from
draughts of air whereby its sensibility would be impaired.

Another form of conditioning apparatus of somewhat different shape is shown in Fig. 18.
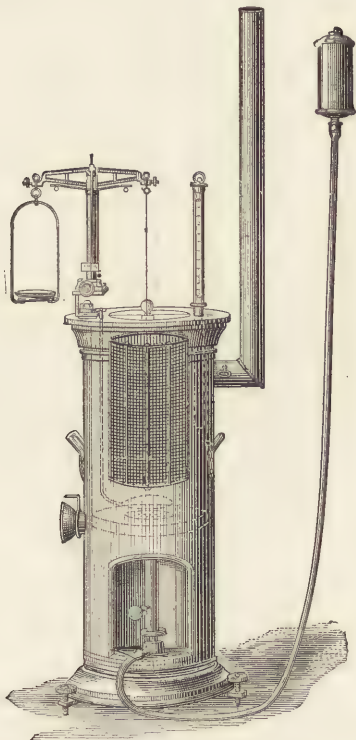
FIG. 18.—Another Form of Conditioning Apparatus.

6. Calculations Involved in Conditioning.—In the conditioning of wool (or of any other textile material), there are certain calculations necessary which it may be advisable at this point to explain. The two principal calculations to be made involve the determination of the percentage of moisture based on the weight of the material as taken for the test (that is, on its moist weight), and then the determination of the conditioned weight of the material based on a definite percentage allowance of "regain," this percentage being calculated on the dry weight of the material. The different problems in conditioning will now be taken up.*

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* See Persoz, *Essai des Matières Textiles.*

(1) If a weight (w) of material after drying shows a weight (a), what percentage (x) of moisture does it contain?

$$w - a = \text{loss in weight on drying} = \text{moisture.}$$

$$\frac{w}{w-a} \times 100 = x, \text{ per cent. of moisture.}$$

(2) If a quantity of material of weight (w) contains x per cent. of moisture, what is its dry weight (a)?

$$a = w \left(1 - \frac{x}{100} \right).$$

(3) If from a weight (W) of material there is taken a sample of weight (w) and the dried weight of this is found to be (a), what will be the conditioned weight (C) of the material, allowing a regain of (R) per cent.?

The dry weight (A) of the entire material will be

$$A = W \times \frac{a}{w},$$

and the conditioned weight will be

$$C = W \times \frac{a}{w} \left(1 + \frac{R}{100} \right).$$

(4) A substance is conditioned with a regain of (R) per cent., what percentage of moisture (x) does it contain?

We have the proportion

$$\frac{100 + R}{R} = \frac{100}{x};$$

therefore

$$x = \frac{100R}{100 + R}.$$

The following table shows the percentage of moisture in any material corresponding to a definite percentage of regain.

Per Cent. Regain.	Per Cent. of Moisture.	Per Cent. Regain.	Per Cent. of Moisture.
5	4.76	12	10.71
6	5.66	12.5	11.11
7	6.54	13	11.50
7.5	6.98	14	12.28
8	7.41	15	13.04
8.5	7.83	16	13.79
9	8.26	17	14.53
10	9.09	18	15.25
11	9.91	19	15.97
		20	16.67

(5) If a material contains (x) per cent. of moisture, what will be the corresponding percentage of regain (R)?

This is the reverse of the previous problem. We have

$$R = \frac{100x}{100 - x}.$$

The following table shows the percentage of regain of any material corresponding to a definite percentage of moisture.

Per Cent. of Moisture.	Per Cent. Regain.	Per Cent. of Moisture.	Per Cent. Regain.
5	5.26	13	14.94
6	6.38	14	16.28
7	7.53	15	17.65
8	8.70	16	19.05
9	9.89	17	20.48
10	11.11	18	21.95
11	12.36	19	23.46
12	13.64	20	25.00

(6) If a material is required to possess a definite conditioned weight (C), what percentage of regain (R) must be applied to the dry weight (a)?

We have the proportion

$$\frac{a}{C-a} = \frac{100}{R};$$

therefore

$$R = 100\frac{C-a}{a}.$$

(7) If the dry weight (a) of any material is given, what quantity of water (q) would it have to absorb in order to contain (x) per cent.?

We have the proportion

$$\frac{100-x}{x} = \frac{a}{q};$$

therefore
$$q = \frac{ax}{100-x}.$$

The weight (W) of the material after absorbing the moisture would be

$$a+q,$$

or
$$W = \frac{100a}{100-x}.$$

(8) If the dry weight (a) of a material is given, what would be its conditioned weight (C), allowing (R) percentage of regain?

We have in this case

$$C = a\left(1 + \frac{R}{100}\right).$$

(9) If the conditioned weight (C) of a material is given with a percentage of regain (R), what is its dry weight (a)?

From the previous formula we have

$$a = \frac{100C}{100+R}.$$

(10) If the percentage of moisture (x) is known in a material, what will be the conditioned weight (C), allowing a regain of (R) per cent.?

The dry weight (a) will be

$$a\left(1 - \frac{x}{100}\right).$$

Therefore the conditioned weight with (R) per cent. regain will be

$$C = a\left(1 - \frac{x}{100}\right)\left(1 + \frac{R}{100}\right).$$

(11) If the original weight (W) of a material is known and also its conditioned weight (C), what percentage difference in weight (D) would there be between the original weight and the conditioned weight?

We have the proportion

$$\frac{W}{W-C} = \frac{100}{D};$$

therefore

$$D = \frac{100(W-C)}{W}.$$

There would be a gain or loss by conditioning according to whether (W) is greater or less than (C).

(12) If the conditioned weight (C) of a material is given and also its percentage difference (D) on conditioning, find the original weight (W) of the substance.

From the previous formula we have

$$W = \frac{100C}{100-D}.$$

(13) If the original weight (W) of a material is known and also the percentage difference (D) on conditioning, find the conditioned weight (C).

From the previous formula we have

$$C = \frac{W(100-D)}{100}.$$

(14) If a material contains (x) per cent. of moisture, calculate the difference (d) between its original weight (W) and its conditioned weight (C) with a regain of (R) per cent.

This difference is

$$d = W - C,$$

and from the formula under (10) we have

$$d = W - W\left(1 - \frac{x}{100}\right)\left(1 + \frac{R}{100}\right);$$

hence $\qquad\qquad d = \dfrac{W[(100+R)x - 100R]}{10,000}.$

If (W) in this formula is taken as equal to 100, the expression becomes simplified to

$$d = D = \left(1 + \frac{R}{100}\right)x - R.$$

According to the value of (x) this difference will be positive or negative; that is to say, the material will lose or gain by conditioning.

If $\qquad\qquad x$ is greater than $\dfrac{100R}{100+R}$

there will be a loss.

If $\qquad\qquad x = \dfrac{100R}{100+R}$

the fibre will be in its conditioned state.

Finally, if $\qquad x$ is less than $\dfrac{100R}{100+R}$

the material will gain in weight by conditioning.

(15) If the difference (d) between the original weight (W) of a material and its conditioned weight (C) at a regain of (R) per cent. is known, find the percentage of moisture (x) in the material.

This is the reverse of the preceding problem and may be solved by taking the reciprocal of the formula for (*d*), as follows:

$$x = \frac{100(WR + 100d)}{W(100 + R)}.$$

If we take the original weight as equal to 100 and call (*D*) the corresponding difference, the expression becomes

$$x = \frac{100(R + D)}{100 + R}.$$

It is necessary to remember in these formulas that the value of (*d*) or (*D*) is positive only if the original weight is greater than the conditioned weight; if the contrary is the case, the difference will be of a negative value. For example, a sample of wool *loses* 2 per cent. on conditioning at 15 per cent. regain; hence it contains

$$\frac{100(15 + 2)}{100 + 15} = 14.7 \text{ per cent. moisture,}$$

whereas if it *gains* 2 per cent. in weight by conditioning, we have

$$\frac{100(15 - 2)}{100 + 15} = 11.3 \text{ per cent. moisture.}$$

(16) A sample of material shows a difference in weight of (*D*) per cent. on conditioning at (*R*) per cent. regain, what difference (*D'*) would there be if conditioned at a regain of (*R'*) per cent.?

If we call the dry weight (*a*), then

$$D = 100 - a\left(1 + \frac{R}{100}\right),$$

$$D' = 100 - a\left(1 + \frac{R'}{100}\right).$$

Hence, by eliminating (a), we have

$$D' = \frac{(100+R')D - 100(R'-R)}{100+R}.$$

This problem will often arise in practice where two different sets of regains are to be allowed. For example, a sample of wool conditioned at a regain of 15 per cent. loses 0.4 per cent. in weight, how much would it lose if the regain allowed was 17 per cent.?

$$D' = \frac{(117 \times 0.4) - (100 \times 2)}{115} = -1.3 \text{ per cent.;}$$

that is to say, the fibre would *gain* 1.3 per cent. in weight.

(17) A sample of material on conditioning at a regain of (R) per cent. shows a loss of (D) per cent., what regain would have to be adopted in order that the loss may be (D') per cent.?

From the previous formula we have

$$R' = \frac{100(D+R) - D'(100+R)}{100-D}.$$

(18) If the conditioned weight (C) at a regain of (R) per cent. is known, calculate the conditioned weight (C') at a regain of (R') per cent.

From the formula under (8) we have

$$\frac{C}{C'} = \frac{100+R}{100+R'};$$

hence

$$C' = C\frac{100+R'}{100+R}.$$

(19) In a textile material consisting of two kinds of fibres, if the percentage conditioned amounts of the two fibres are known, (C) and (C'), and their respective regains are (R) and

(R'), what will be the average regain (r) and the average amount of moisture (x) in the mixture?

If (C) and (C') are the conditioned weights of the two fibres, their dry weights (A) and (A') would be

$$A = \frac{100C}{100+R} \quad \text{and} \quad A' = \frac{100C'}{100+R'};$$

the average moisture would be

$$x = 100 - \left(\frac{100C}{100+R} + \frac{100C'}{100+R'} \right);$$

hence

$$x = 100 \left[1 - \left(\frac{C}{100+R} + \frac{C'}{100+R'} \right) \right].$$

The average regain would be

$$r = \frac{100x}{100-x}.$$

For example, suppose we have conditioned a yarn composed of 65 per cent. of wool and 35 per cent. of cotton, with respective regains of 15 and 7 per cent.   Then

$$x = 100 \left[1 - \left(\frac{65}{115} + \frac{35}{107} \right) \right],$$

$x = 9.6$ per cent. moisture,

$r = 10.6$ per cent. average regain.

(20) In a textile of mixed fibres if the proportion (P) and (P') of the two fibres is known on the dry weight (A), together with

the moisture (x) lost on drying, what would be the conditioned weight (C) of the material, allowing (R) and (R') respectively as the regains for the two fibres?

We have

$$\frac{P}{100}A = \text{amount of first fibre,}$$

$$\frac{P'}{100}A = \text{amount of second fibre,}$$

and

$$\left(\frac{PA}{100} \times \frac{R}{100}\right) + \frac{PA}{100} = \text{conditioned weight of first fibre.}$$

$$\left(\frac{P'A}{100} \times \frac{R'}{100}\right) + \frac{P'A}{100} = \text{conditioned weight of second fibre.}$$

Adding these two terms gives us

$$A\left(1 + \frac{PR + P'R'}{10000}\right) = \text{conditioned weight of entire material.}$$

For example, suppose a yarn contains 60 per cent. of wool and 40 per cent. of cotton on a dry weight of 85 lbs., allowing respective regains of 15 and 7 per cent., what would be the conditioned weight of the yarn?

$$85\left(1 + \frac{60 \times 15 + 40 \times 7}{10000}\right) = 85 \times 1.118 = 94.83 \text{ lbs.}$$

TABLE SHOWING THE CONDITIONED WEIGHT OF 100 LBS. OF ANY MATERIAL WITH REGAINS OF 7, 11, AND 15 PER CENT., CONTAINING DIFFERENT AMOUNTS OF MOISTURE.

Per Cent. Moisture.	Conditioned Weight, Regains.			Per Cent. Moisture.	Conditioned Weight, Regains.		
	7 Per Cent.	11 Per Cent.	15 Per Cent.		7 Per Cent.	11 Per Cent.	15 Per Cent.
5.0	101.65	105.45	109.25	9.7	96.62	100.23	103.84
.1	101.54	105.34	109.14	.8	96.51	100.12	103.73
.2	101.44	105.23	109.02	.9	96.41	100.01	103.61
.3	101.33	105.12	108.91	10.0	96.30	99.90	103.50
.4	101.22	105.01	108.79	.1	96.19	99.79	103.38
.5	101.12	104.90	108.68	.2	96.09	99.68	103.27
.6	101.01	104.78	108.56	.3	95.98	99.57	103.16
.7	100.90	104.67	108.45	.4	95.87	99.46	103.04
.8	100.80	104.56	108.33	.5	95.77	99.34	102.93
.9	100.69	104.45	108.22	.6	95.66	99.23	102.81
6.0	100.58	104.34	108.10	.7	95.55	99.12	102.70
.1	100.48	104.23	107.99	.8	95.45	99.01	102.58
.2	100.37	104.12	107.87	.9	95.34	98.90	102.47
.3	100.26	104.01	107.76	11.0	95.23	98.79	102.35
.4	100.15	103.90	107.64	.1	95.12	98.68	102.24
.5	100.05	103.79	107.53	.2	95.02	98.57	102.12
.6	99.94	103.67	107.41	.3	94.91	98.46	102.01
.7	99.83	103.56	107.30	.4	94.81	98.35	101.89
.8	99.72	103.45	107.18	.5	94.70	98.23	101.78
.9	99.62	103.34	107.07	.6	94.59	98.12	101.66
7.0	99.51	103.23	106.95	.7	94.48	98.01	101.55
.1	99.40	103.12	106.84	.8	94.37	97.90	101.43
.2	99.30	103.01	106.72	.9	94.27	97.79	101.32
.3	99.19	102.90	106.61	12.0	94.16	97.68	101.20
.4	99.08	102.79	106.49	.1	94.05	97.57	101.08
.5	98.98	102.68	106.38	.2	93.95	97.46	100.97
.6	98.87	102.56	106.26	.3	93.84	97.35	100.85
.7	98.76	102.45	106.15	.4	93.73	97.24	100.74
.8	98.66	102.34	106.03	.5	93.62	97.12	100.62
.9	98.55	102.23	105.92	.6	93.52	97.01	100.51
8.0	98.44	102.12	105.80	.7	93.41	96.90	100.39
.1	98.34	102.01	105.69	.8	93.30	96.79	100.28
.2	98.23	101.90	105.57	.9	93.19	96.68	100.16
.3	98.12	101.79	105.46	13.0	93.09	96.57	100.05
.4	98.01	101.68	105.34	.1	92.98	96.46	99.94
.5	97.90	101.57	105.23	.2	92.88	96.35	99.82
.6	97.80	101.45	105.11	.3	92.77	96.24	99.71
.7	97.69	101.34	105.00	.4	92.66	96.13	99.59
.8	97.58	101.23	104.88	.5	92.55	96.01	99.48
.9	97.48	101.12	104.77	.6	92.45	95.90	99.36
9.0	97.37	101.01	104.65	.7	92.34	95.79	99.25
.1	97.26	100.90	104.53	.8	92.23	95.68	99.13
.2	97.16	100.79	104.42	.9	92.12	95.57	99.02
.3	97.05	100.68	104.30	14.0	92.02	95.46	98.90
.4	96.94	100.57	104.19	.1	91.91	95.35	98.78
.5	96.84	100.46	104.07	.2	91.81	95.24	98.67
.6	96.73	100.34	103.96	.3	91.70	95.13	98.56

TABLE SHOWING THE CONDITIONED WEIGHT—(*Continued*).

Per Cent. Moisture.	Conditioned Weight, Regains.			Per Cent. Moisture.	Conditioned Weight, Regains.		
	7 Per Cent.	11 Per Cent.	15 Per Cent.		7 Per Cent	11 Per Cent	15 Per Cent.
14.4	91.59	95.02	98.44	17.8	87.95	91.24	94.53
.5	91.49	94.90	98.33	.9	87.85	91.13	94.42
.6	91.38	94.79	98.21	18.0	87.74	91.02	94.30
.7	91.27	94.68	98.10	.1	87.63	90.91	94.18
.8	91.16	94.57	97.98	.2	87.52	90.80	94.07
.9	91.05	94.46	97.87	.3	87.42	90.69	93.96
15.0	90.95	94.35	97.75	.4	87.31	90.58	93.84
.1	90.84	94.24	97.64	.5	87.21	90.46	93.73
.2	90.74	94.13	97.52	.6	87.10	90.35	93.61
.3	90.63	94.02	97.41	.7	86.99	90.24	93.50
.4	90.52	93.91	97.29	.8	86.88	90.13	93.38
.5	90.42	93.79	97.18	.9	86.78	90.02	93.27
.6	90.31	93.68	97.06	19.0	86.67	89.91	93.15
.7	90.20	93.57	96.95	.1	86.56	89.80	93.04
.8	90.09	93.46	96.83	.2	86.45	89.69	92.92
.9	89.98	93.35	96.72	.3	86.35	89.58	92.81
16.0	89.88	93.24	96.60	.4	86.24	89.47	92.69
.1	89.77	93.13	96.48	.5	86.13	89.36	92.58
.2	89.67	93.02	96.37	.6	86.02	89.24	92.46
.3	89.56	92.91	96.26	.7	85.92	89.13	92.35
.4	89.45	92.80	96.14	.8	85.81	89.02	92.23
.5	89.34	92.68	96.03	.9	85.71	88.91	92.12
.6	89.24	92.57	95.91	20.0	85.60	88.80	92.00
.7	89.13	92.46	95.80	.1	85.49	88.69	91.88
.8	89.02	92.35	95.68	.2	85.38	88.58	91.77
.9	88.92	92.24	95.57	.3	85.28	88.47	91.66
17.0	88.81	92.13	95.45	.4	85.17	88.36	91.54
.1	88.71	92.02	95.34	.5	85.06	88.25	91.43
.2	88.60	91.91	95.22	.6	84.95	88.13	91.31
.3	88.49	91.80	95.11	.7	84.85	88.02	91.20
.4	88.38	91.69	94.99	.8	84.74	87.91	91.08
.5	88.28	91.57	94.88	.9	84.63	87.80	90.97
.6	88.17	91.46	94.76	21.0	84.53	87.69	90.85
.7	88.06	91.35	94.65				

CHAPTER IV.

SHODDY AND WOOL SUBSTITUTES.

1. Varieties of Shoddy.—Besides the natural varieties of wool which find applications in the textile industries we have a large quantity of recovered wool employed as a textile fibre. This is obtained by tearing up woolen rags and waste, converting it back into the loose fibre and spinning it over again, either alone or in admixture with varying proportions of pure fibre or fleece-wool. This *artificial wool*, or *wool substitute*, as it is frequently called, is also obtained from rags and waste containing wool and cotton, or even silk; the vegetable fibre being destroyed by chemical treatment, leaving the animal fibre to be extracted and used again. On this account it is sometimes known as *extract wool*. The industry of converting recovered fibre into yarns and fabrics has assumed of late enormous proportions, and nearly all cheap woolen goods contain a high percentage of these wool substitutes in their composition. Depending on its source of production, this recovered wool will vary largely in its quality, and according to its origin and nature it is classed under several names, chief among which are the following:

(*a*) *Shoddy*. Though this name is frequently applied to all manner of recovered fibre, it is more specifically used to designate that which is derived from all-wool rags or waste which have not been felted, also from knit goods. This yields the best quality of fibre, the average length of which is about one inch. In many cases it is almost equal in quality to a fair grade of fleece-wool, and is used in the production of many high-grade fabrics.

(*b*) *Mungo* refers to the fibre obtained from woolen material which has been fulled or felted considerably; to disintegrate the

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rags the fibres must be torn apart, and consequently it yields fibres of shorter staple and less value than the preceding.

(*c*) *Extract wool* is that obtained from mixed wool and cotton rags and waste, and has to undergo the process of carbonization, whereby the vegetable fibre is destroyed.* It is sometimes called alpaca, and varies much in its length of staple and other qualities. Besides these well-known varieties of recovered wool there are a number of others to be met with in commerce, such as *Thibet wool*, which is usually obtained from light-weight cloth clippings and waste. *Cosmos fibre* is a very low-grade material, usually containing no wool at all, being made by converting flax, jute, and hemp fabrics back to the fibre.† Even the short down obtained in the shearing of woolen cloths is used, it being employed as a filler. The process of using it is called "impregnating," and consists in fulling the short waste into the cloth on the under side.

2. Examination of Shoddy.—Woolen fibres consisting of shoddy usually offer a very characteristic appearance under the microscope, sufficient, at least, to distinguish them from fibres of new wool. A sample of shoddy generally shows the presence of other fibres besides wool, and fibres of silk, linen, and cotton are frequently to be observed (Fig. 19). Also, the colors of the different woolen fibres present are frequently quite varied, so that shoddy usually presents a multi-colored appearance under the microscope. A very striking appearance, also, is the simultaneous occurrence of dyed and undyed fibres; the diameters of the fibres will also vary between large limits, the variation in this respect being much more than with fleece wool. Some samples of shoddy will also show a large number of torn and broken fibres, and usually the external scales are rougher and more prominent.

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* This process is generally carried out by steeping the rags in a solution of sulphuric acid (6° Tw.) at 140° to 180° F. and then drying, whereupon the vegetable fibres are decomposed and are easily dusted out by willowing, the wool fibres being scarcely affected. The excess of acid is then removed by treatment with soda-ash and washing The fibres obtained are sometimes over one inch in length.

† *Peat fibre* is a product obtained from partially decomposed peat. It is mixed with wool for yarns to be used in the manufacture of horse-cloths, mats, etc. *Wood-wool* is a somewhat similar product obtained from the long bleached fibres of wood.

It must be borne in mind, however, that pure wool may also show the presence of small quantities of vegetables fibres at times. These often arise from the occurrence of burrs (bristly and barbed seeds of various plants) in the original fleece. South American wools are especially liable to contain such burrs; in many cases these are incompletely removed, and may ultimately appear even
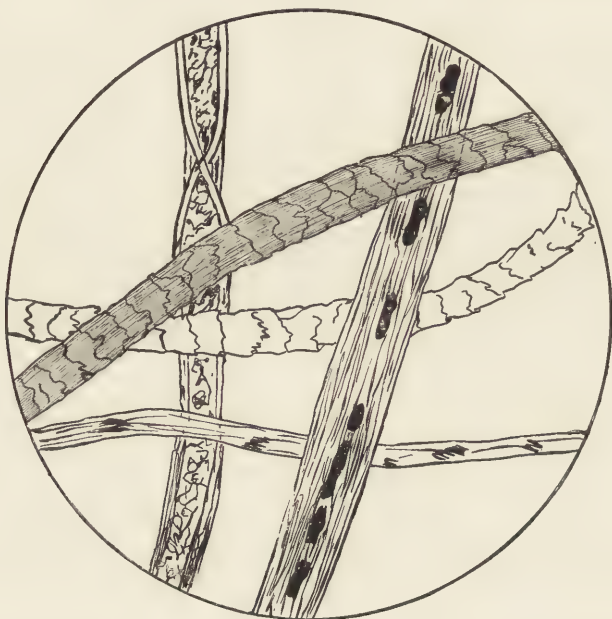
FIG. 19.—Microscopic Appearance of Shoddy, showing the varied Character of the Fibres. (×350.) (Micrograph by author.)

in the woven cloth. This frequently explains the existence of short fibres or vascular bundles of vegetable matter in cloth. Isolated fibres of woody tissue and cotton may also accidentally creep in through a variety of causes. According to Höhnel, samples of pure wool may easily contain as much as $\frac{1}{2}$ per cent. of vegetable fibre. The latter authority also states that the vegetable fibres of shoddy, as a rule, are removed by carbonizing; hence the absence of cotton, linen, etc., must not be taken as a criterion to distinguish between pure wool and shoddy. When,

however, cotton (always dyed) or cosmos fibre occurs in at least a quantity of one per cent., this may be taken as a direct indication of the presence of shoddy, as it would scarcely ever happen that pure wool is adulterated with cotton; this only happens by admixture with shoddy wool. Undyed cotton, unless present in considerable amount, cannot be considered as a suspicious component.

The determination of the length of staple is also a rather unreliable indication as to the presence of shoddy, for there are varieties of shoddy wools which are longer in staple than many fleece-wools; and also woven goods, though composed entirely of fleece-wool, may show the presence of a large number of short fibres caused by the shearing of the surface of the cloth, and by the tearing of the fibres in heavy fulling.

Where woolen cloth has been impregnated or filled with short fibres obtained from clippings, such may usually be recognized by teasing the sample out with a stiff bristle-brush. Good cloth should not yield over $\frac{1}{2}$ per cent. of clipped fibres from both sides. When the amount of such fibres is at all considerable, they may be used as serviceable material to test microscopically for shoddy, as they are most likely to be made up of this character of wool.

Fine fleece-wools hardly ever show the absence of epidermal scales (though this is frequently the case with coarse wools); hence if examples of such fine wools are found showing a lack of epidermis, it may usually be taken as an indication of shoddy.

Höhnel, however, calls attention to the fact that the following conditions previous to the manufacturing process itself have considerable influence on the good structure and integrity of the wool fibre: badly cut staple, lack of attention in raising the sheep, poor pasturage, sickness of the animal, the action of urine, snow, rain, dust, etc., packing the wool in a moist condition, rapid and frequent changes of moisture and temperature, the use of too hot or too alkaline baths in scouring, scouring with bad detergents, etc. These influences may lead to the partial removal of the epidermis, and to the softening and breaking of the ends of the fibre. There must also be considered the influence of wil-

lowing, carding, combing, spinning, weaving, gigging, fulling, acidifying, washing, shearing, pressing, etc., from which it is easy to understand why even fibres of fleece-wool may show the entire absence of epidermis. Höhnel also criticises other alleged characteristics of shoddy, such as torn places in the fibre, unevenness in diameter, etc., claiming that these can hardly be taken as an indication of shoddy, because such marks are often regularly present in many fleece-wools. Most samples of shoddy, in fact, show scarcely any structural differences from ordinary fleece-wool. The ends of shoddy fibres, however, usually present a torn appearance; at least there is a great predominance of such fibres in shoddy, whereas in fleece-wool this appearance is seldom to be observed, the end of the fibre being cut off sharply. The appearance of the torn fibres may be easily observed under the microscope; the epidermis being entirely torn away, as well as the marrow which is sometimes present, while the fibrous cortical layer is frayed out like the end of a brush. This appearance can usually be rendered more distinct by previously soaking the fibres in hydrochloric acid. Sheared fibres are recognized by being very short and by having both ends sharply cut off.

The color of the fibres is also a characteristic appearance of shoddy, as the majority of shoddy is made up of variously colored wools. It is of rare occurrence that rag-shoddy possesses a single uniform color. Hence if a sample of yarn, possessing a single average color, on examination reveals the presence of variously colored fibres, it is almost a positive indication of shoddy. In this connection it must not be forgotten, however, that frequently differently colored wools are mixed together previous to spinning, to make so-called "mixes." As a rule, however, only two to three colors are used together; therefore a purposely mixed yarn of this description is not likely to be confounded with a shoddy yarn where individual fibres of a large number of colors are nearly always shown.

CHAPTER V.

MINOR HAIR FIBRES.

1. The Minor Hair Fibres.—Besides the fibre obtained from the domestic sheep, there are large quantities of hair fibres employed in the textile industries and obtained from related species of animals, such as goats, camels, etc. As these are all more or less utilized in conjunction with wool itself, and are subjected to similar operations in manufacturing, it will not be out of place to consider them at this point. The chief among these related fibres are mohair, cashmere, alpaca, cow-hair, and camel-hair.

2. Mohair.—This fibre is obtained from the Angora goat, an animal which appears to be indigenous to western Asia, being largely cultivated in Turkey and neighboring provinces. The fleece is composed of very long fibres, fine in staple, and with little or no curl. The fibre is characterized by a high silky lustre. Mohair is now grown to a considerable extent in the Western States, principally Oregon, California, and Texas, the goats having originally been imported from Turkey; there is also a large quantity of mohair grown in Cape Colony. The principal mohair clips (1902) are as follows:

Turkey. . . . . 8,500,000 lbs.
Cape Colony. . . . . 7,500,000 "
United States. . . . . 1,250,000 "

The principal use of mohair is for the manufacture of plushes, braids, fancy dress fabrics, felt hats, and linings. The character of fabric in which it may be employed is rather limited on account of the harsh wiry nature of the mohair fibre, and the fact that it will not felt to any degree. Domestic mohair (Ameri-

can) has only about two-thirds of the value of the foreign fibre; mohair in general has quite a large amount of kempy fibre (which will not dye), but the domestic variety contains about 15 per cent. more kemp than the foreign, hence the lower value of the former. Another reason for this lessened value is that foreign mohair always represents a full year's growth (the fibres being 9 to 12 ins. in length), whereas a great deal of domestic mohair is shorn twice a year. This is especially true of that grown in Texas; the hair commences to fall off the goats in that district if allowed to grow for the full year. In judging of the quality of mohair, the length and lustre are of more value than the fineness of staple. The finest grades of domestic mohair come from Texas, that from Oregon and California being larger and coarser. In Oregon the fleece is grown for a full year, and consequently the fibre is very long. The average weight of the fleece from Oregon goats is 4 lbs., while in Texas it is only $2\frac{1}{4}$ lbs. Foreign mohair varies much in quality, depending upon the district in which it is grown; as a rule, the finer varieties are shorter in staple, the finest being about 9 ins. in length. Foreign mohair can be spun to as high a count as 60's, whereas the finest quality of domestic mohair can only be spun to as high as 40's. The coarsest varieties of mohair are used in carpets, low-grade woolen fabrics, and blankets.

Microscopically, the mohair fibre is possessed of the following characteristics: The average length is about 18 cm., and the diameter about 40 to 50 μ, and very uniform throughout the entire length (see Fig. 20). The epidermal scales can only be observed with difficulty, as they are very thin and flat, though regular in outline. They are also very broad, a single scale frequently surrounding the entire fibre; the edge of the scale is usually finely serrated. The best grades of fibres show no medulla, but there are usually to be found (especially in domestic mohair) coarse, thick fibres possessing a broad medullary cylinder, thus resembling the structure of ordinary goat-hair, from which, however, they are to be distinguished by being more slender and more uniform in their diameter. Longitudinally, the fibre exhibits coarse, fibrous striations, approximating the appearance of broad and regularly occurring fissures. Due to the fact that the surface scales

lie very flat and do not project over one another, the edge of the fibre is very smooth, showing scarcely any serrations at all, which accounts for its utter lack of felting qualities. The outer end of the fibre is either slightly swollen or blunt, but never pointed. When viewed under polarized light the fibres occasionally show the presence of a medullary canal, which appears as a hollow space, giving an illumination somewhat resembling that of a
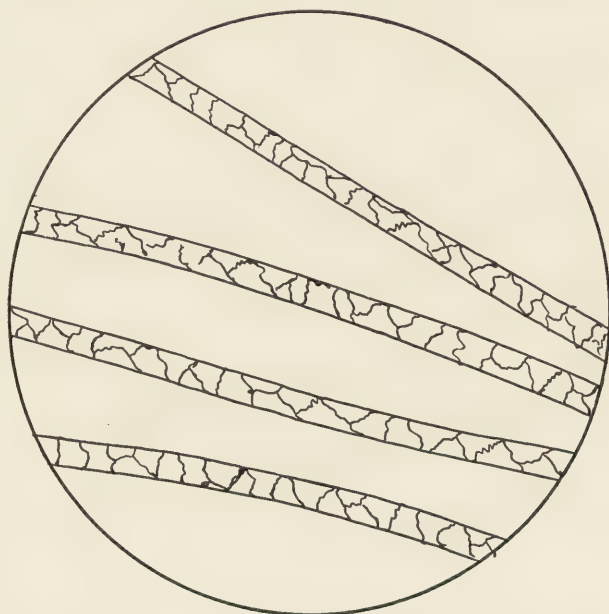
FIG. 20.—Mohair Fibres. (×350.) (Micrograph by author.)

bast fibre, and covering from one-fourth to one-half of the diameter.

3. Cashmere is remarkable for its softness, and is much used in the woolen industry for the production of fabrics requiring a soft nap. Cashmere is the fibre employed in the manufacture of the famous Indian shawls. There are two qualities of cashmere wool, the one consisting of the fine, soft down-hairs and the other of long, coarser beard-hairs. The former are from $1\frac{1}{4}$ to $3\frac{1}{2}$ ins. in length and 13 μ in diameter, while the latter are from $3\frac{1}{2}$ to $4\frac{1}{2}$ ins. in length by 60 to 90 μ in diameter. The wool-hairs show

visible scales but no definite medulla, whereas the beard-hairs possess a well-developed medulla. The cortical layer is coarsely striated and shows characteristic fissures. At the point of the fibre the epidermal scales are either entirely absent or are so thin as to be scarcely visible. The fibre is very cylindrical; the scales have their free edge finely serrated, and the edge of the fibre also presents the same appearance.

Besides mohair and cashmere, the hair of the ordinary **goat** is also used at times. It has the following characteristics (Höhnel):
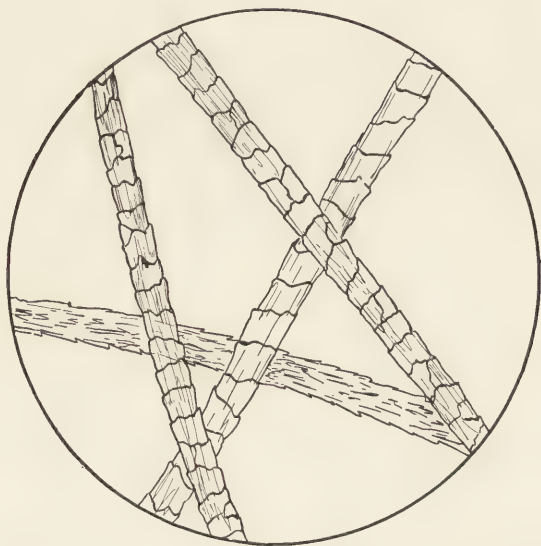
FIG. 21.—Wool-hairs of Cashmere. ($\times$350.) (Micrograph by author.)

It is white, yellow, brown, or black in color, and generally from 4 to 10 cm. long. It consists almost entirely of wool-hairs, which, like pulled wool, nearly always show the hair root. The average hair exhibits the following structure (see Fig. 21): At the base it is about 80 to 90 μ thick; the root is about $\frac{1}{3}$ mm. long; the marrow is just visible at the root, then rapidly increases in thickness, so that a few millimeters from the base it is 50 μ thick, where the thickness of the hair amounts to from 80 to 90 μ. The cortical layer from this point on forms a very thin cylinder. The

cross-section is round; the epidermis consists of broad scales about 15 μ long, the forward edges of which are scarcely thickened, but appear as if terminating in a sharp line; furthermore they are not serrated. The medullary cells are thick-walled, narrow, and flattened. Towards the end the hair is very brittle and easily broken. Colored goat-hair shows the presence of pigment-matter in all of its tissues; in such fibres the marrow appears black.

4. Alpaca and its varieties *vicuña* and *llama* have the disadvantage of being mostly colored from brown to black. Though largely used in South America for the production of various fabrics, they do not find much application in the general textile industry. There is another product in trade which goes by the name of vicuña (French *vicogne*) which must not be confused with the true South American fibre, it being simply a trade name for a mixture of cotton and wool. The name alpaca is also given to a variety of wool substitute. The South American wools often give rise to wool-sorter's disease to those handling them. This disease is anthrax and is caused by the presence of a certain microbe in the fibre. Wool-sorter's disease is caused by *Bacillus anthracis,* which may enter the system either by the skin (through the medium of an abrasion or cut) or by the internal organs, being introduced with the food. In the former case it gives rise to pustules, which become painful and cause excessive perspiration, fever, delirium, and sundry disorders. In the latter case it gives rise to the most serious results, leading to blood-poisoning and inflammation of the lungs, which often prove speedily fatal.

True alpaca is obtained from the cultivated South American goat *Auchenia paco*. It occurs in all varieties of colors, from white, through brown, to black. The reddish-brown and not the white variety, however, is the most valuable. Like other goat-hairs, alpaca consists of two varieties of fibres, a soft wool-hair and a stiff beard-hair. The wool-hairs of the reddish-brown variety are from 10 to 20 cm. in length and from 12 to 35 μ in diameter (see Fig. 22). The fibre is very smooth, the serrations on the edge being faint and indistinct, and the scales are almost

imperceptible and, in many cases, apparently absent altogether; the diameter is also very uniform, and there are coarse brown longitudinal striations but no medulla, though isolated medullary cells are at times observed. The wool-hairs of the white variety are very distinctly serrated on the edge, and the fibre is not so uniformly thick. The beard-hairs of the brown variety are comparatively few in number, are from 5 to 6 mm. in length and about 60 μ
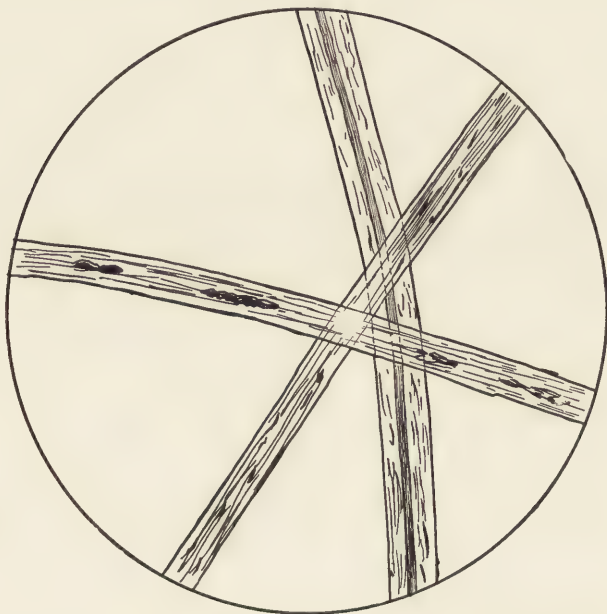
FIG. 22.—Alpaca Fibres. ($\times$ 350.) (Micrograph by author.)

in diameter, and the latter is very uniform. A very broad continuous medullary cylinder is present, 45 to 50 μ wide; the medullary cells are very indistinct, but are filled with coarse granules of matter. The cortical layer shows occasional fissures, and the brown coloring-matter is principally distributed through the external cortical layer, though very irregularly. The beard-hairs of the white variety also occur rather sparingly; they are from 20 to 30 cm. in length, and 35 μ in thickness at the lower end and about 55 μ towards the upper end. The medulla is broad and continuous, and nearly always filled with a coarsely granulated matter of a

gray color. The medulla consists of a single row of short cylin-
drical cells, but, as the walls are very thin, the cells are to be
seen only with difficulty. The cortical layer is coarsely striated
and frequently shows fibrous fissures; the edge of the fibre is
not sharply serrated.

5. Vicuña Wool is another South American product ob-
tained from *Auchenia viccunia,* the smallest of this general class
of goat-like camels. It is not a cultivated animal, and is evidently
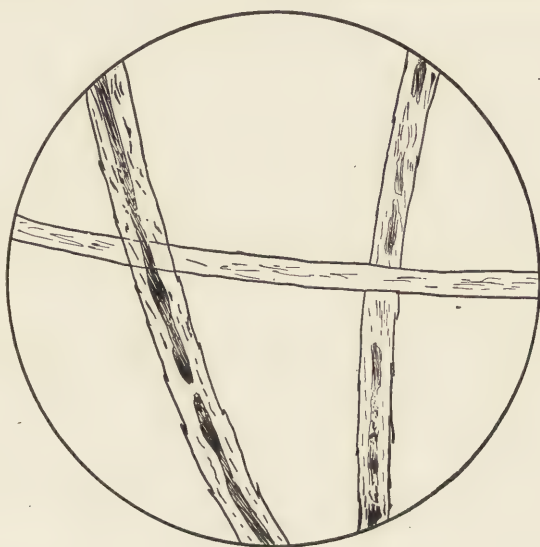
FIG. 23.—Vicuña Fibres. (×350.) (Micrograph by author.)

disappearing, hence the fibre is not met with in trade to any
great extent at the present time. It is a soft, delicate fibre, usually
of a reddish-brown color, and much resembles alpaca. It also
shows the presence of a fine wool-hair and a coarse beard-hair;
the former is from 10 to 20 μ in diameter, while the latter is 75 μ
wide. The scales of the wool-hair are very regular and rather
easy to distinguish, but generally no medulla is to be seen. The
cortical layer is finely striated and frequently contains fibrous
fissures. The beard-hairs, however, show a well-developed
medulla, mostly dark in color. The fibres of the wool-hair are
very uniform in diameter and about 20 cm. in length.

An artificial wool substitute also goes by the name of vicuña or vicogne yarn, but bears no resemblance to the true South American fibre. It consists principally of a mixture of cotton with sheep's wool, but is frequently mixed more or less with wools and coarse beard-hairs of poor spinning qualities obtained from various goats (of Asia Minor), from camels, and from South
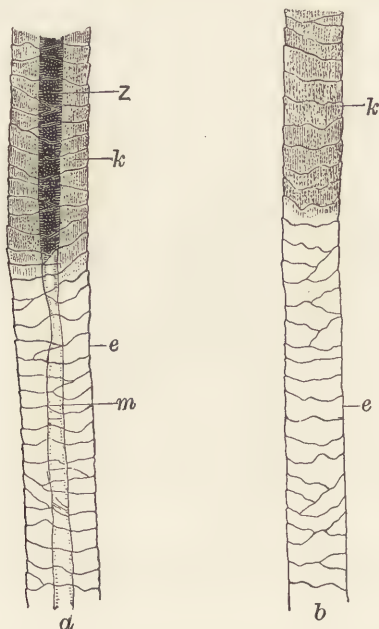
FIG. 24.—Fibres of Alpaca. (Höhnel.) (×350.)

a, beard-hair containing medulla; b, wool-hair free from medulla; e, cusp-like scales, thin and broad; k, granulated streaks on the fibrous layer; m, medullary cylinders; z, small medullary cells.

American wools. It is of poor quality and generally yellowish brown in color. It is only used for felted materials or for very coarse fabrics.

6. The **Llama** fibre exhibits scarcely any visible surface scales, but has well-developed isolated medullary cells. It also consists of two classes of fibres, both of which show longitudinal striations. The wool-hair is from 20 to 35 μ in diameter, while the beard-hair averages 150 μ. The llama wool comes from the *Auchenia llama*,

a cultivated animal. The wool from another variety, *Auchenia huanaco*, is used to some extent in South America, though it seldom appears as such in general trade. This latter animal is not cultivated, but is hunted wild, and is gradually disappearing. Huanaco and llama are nearly always mixed more or less with alpaca and brought into trade under the latter name. There is but little difference to be found among these three fibres, owing to the close relationship of the animals from which they are
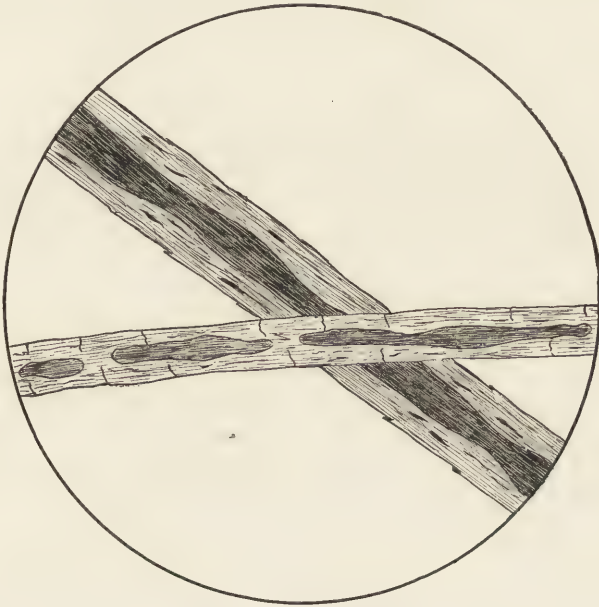
FIG. 25.—Llama Fibres. (×350.) (Micrograph by author.)

derived, and more especially as different portions of the fleece from all varieties of *Auchenia* give wools of entirely different quality, with respect to color, fineness of staple, and purity from coarse stiff hairs; and the corresponding portions from the different animals are usually graded together.

7. Camel-hair is used to quite an extent in clothing material, and is characterized by great strength and softness. It has considerable color in the natural state, which does not appear capable of being destroyed by bleaching; hence camel-hair is either

used in its natural condition or is dyed in dark colors. There are two distinct growths of fibre on the camel: the wool-hair, which is a fine soft fibre, largely employed for making Jäger cloth, and the beard-hair, which is much coarser and stiffer, and is mostly used for carpets, blankets, etc. Both fibres show faint markings of scales on the surface and well-developed longitudinal striations. The beard-hair always exhibits the presence of a well-defined medulla, which is large and continuous, while the
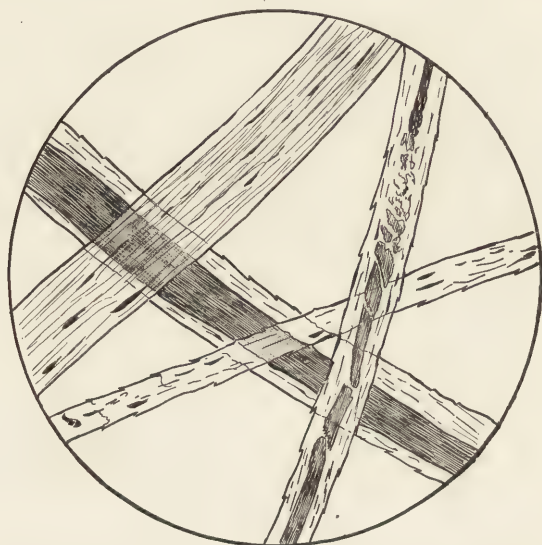
Fig. 26.—Camel-hair. ($\times$350.) (Micrograph by author.)

wool-hair either shows only isolated medullary cells or none at all. The diameter of the wool-hair is from 14 to 28 μ, while the beard-hair averages 75 μ (see Fig. 26). The wool-hairs are about 5 to 6 cm. in length, are rather regularly waved, and are usually yellow to brown in color; while the others are about 10 cm. long and are dark brown to black in color. The epidermal scales of the latter are quite rough, which gives the edge of the fibre a saw-toothed appearance. The presence of large spots, or motes, of brown coloring-matter, especialy in the medulla, is quite char-acteristic. These are usually granular in form. The beard-

hairs of the camel are to be distinguished from corresponding cow-hairs by smaller diameter, thicker epidermis, and narrower medullary çells with thicker walls, which are generally darker in color than the enclosed pigment-matter.

8. Cow-hair is extensively employed as a low-grade fibre for the manufacture of coarse carpet yarns, blankets, and a variety of cheap felted goods. It is seldom used alone, however, on account of its short staple. It comes principally from Siberia. The diameter of cow-hair varies from 84 to 179 μ and the length from $1\frac{1}{2}$ to 5 cm. The fibres occur in a variety of colors, including white, red, brown, and black. In its microscopic appearance the surface of the fibre is rather lustreless; the ends are very irregular, being blunt and divided. The medullary canal is well marked, occupying about one-half the diameter at the base and tapering towards the free end, where it occupies only one-fourth the diameter. Isolated medullary cells are also of frequent occurrence. Cow-hair (including also calf-hair) nearly always shows the hair-root, as the fibres are removed from the hide by liming and pulling.

Cow-hair also shows the presence of three kinds of fibres:

(1) Thick, stiff beard-hairs from 5 to 10 cm. in length, and retaining a long narrow hair follicle; above this is the neck of the hair, containing a medullary cylinder consisting of a single series of cells as well as isolated medullary cells. At this part of the fibre the epidermal scales are very thin and broad, and the forward edges present a serrated appearance; the neck of the hair is about 120 μ in thickness. Above this the hair rapidly increases to about 130 μ in thickness, and the medullary cylinder becomes broad (75 μ) and consists of narrow brick-shaped elements, arranged one on top of the other. The cortical layer is finely striated, the epidermis is indistinct, and the edge of the fibre is smooth. The medullary cells are very thin-walled and contain a considerable amount of finely granulated matter. Towards the pointed end the fibre becomes colorless, and shows distinct fibrous fissures; the medullary cylinder disappears, but the epidermis is not altered. The chief difference between these hairs and the beard-hairs of the goat is that in the former

the medullary cells consist of only a single series, and are very thin-walled, and are also frequently isolated from one another, while they are filled with finely granulated matter.

(2) Soft, fine, beard-hairs possessing the same general structure as the foregoing, but not so thick, the neck of the hair being 75 μ in diameter and not possessing any medulla. Above this the medullary cylinder consists of very thin-walled cells arranged in isolated groups; the epidermal scales overlap one another and
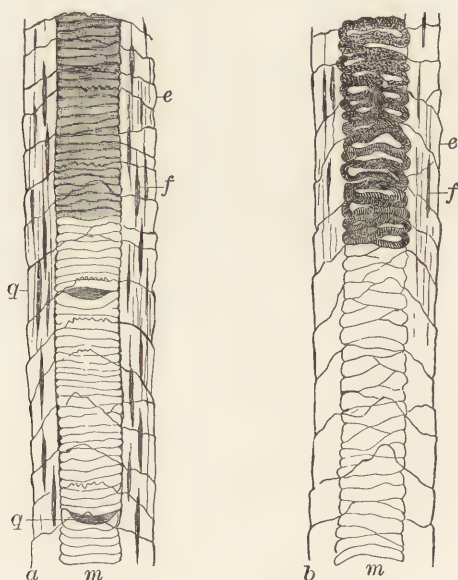
FIG. 27.—*a*, Cow-hair; *b*, Goat-hair. (Höhnel.) (×300.)
q, characteristic fissures in marrow; *m*, marrow or medulla filled with air;
f, fibrous fissures; *e*, tile-shaped scales.

are almost cylindrical, are narrow, and with finely serrated edges. About 1 cm. from the base the medullary cylinder becomes discontinuous and breaks up into isolated medullary cells, which continue until the middle of the fibre is reached, where they disappear completely; towards the pointed end of the fibre they reappear and again become a continuous cylinder, consisting of only a single series of cells, however. These are well filled with a dark medullary substance.

(3) Very fine soft wool-hairs, free from medulla, and at most only 1 to 4 cm. in length, and frequently only 20 μ in thickness. The epidermal scales are rough, causing the edge of the fibre to be uneven and have a serrated appearance. The hairs also show frequent longitudinal fibrous fissures.

Calf-hair has the same general structure and appearance, though there is a greater amount of soft wool-hairs present.

9. Minor Hair Fibres.—*Horse-hair* has a diameter of 80 to 100 μ and a length of 1 to 2 cm. (see Fig. 28). Like cow-hair, it also occurs in a variety of different colors. Horse-hair is more lustrous than the foregoing, however, and though when viewed under the microscope the ends of the fibre are irregular and often forked, they taper off to points. The medullary cylinder is rather large, occupying about two-thirds of the diameter at the base of the fibre and tapering to about one-fourth of the diameter at the free end. The medulla consists of one to two rows of very narrow leaf-shaped cells. Isolated medullary cells are of frequent occurrence, especially at the point. The cortical layer frequently contains numerous short orifices or fissures. These remarks refer to the body-hairs of the horse; the hairs of the tail and mane are much longer, reaching from several inches to a foot or more. They find little

Fig. 28.—Horse-hair. ($\times$90.) (Höhnel.) *m*, broad medullary cylinder; *t*, thin-walled cells of same; *e*, epidermal scales; *f*, fibrous fissures.

or no use in ordinary textiles, but are much used as stuffing materials in the manufacture of upholstery.

Cat-hair varies in diameter from 14 to 34 μ and in length from 1 to 2 cm. The fibres occur in a variety of colors and have a good lustre. The ends are quite regular and very pointed. The medullary canal contains a single series of regular cells occupying one-half to three-fifths of the diameter of the fibre. The cortical layer is well developed, and its inner face is grooved

so as to fit over the medullary cells. There is a thin irregular epidermis which envelops the fibre (see Fig. 29).

Rabbit-hair fibres are usually light brown in color and meas-
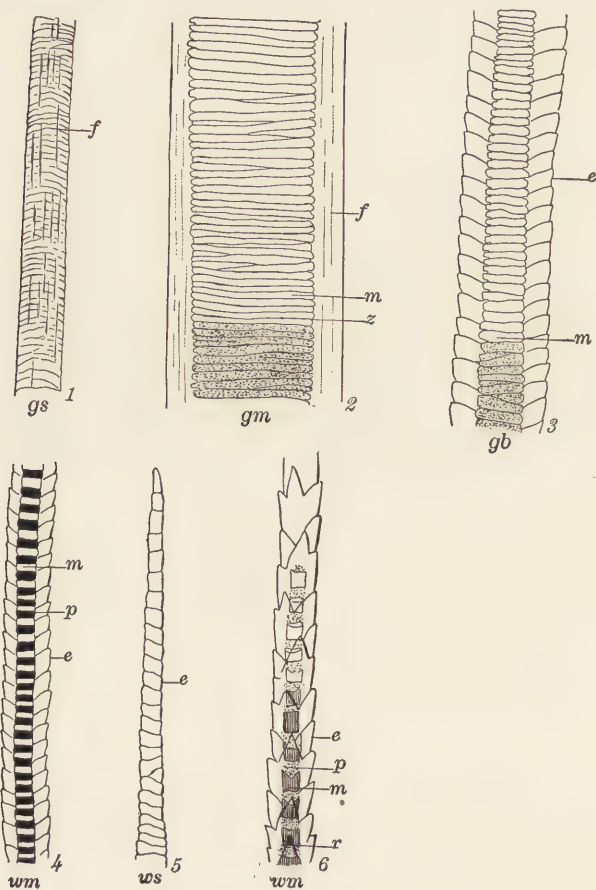
FIG. 29.—Hairs of Cat. (×340.) (Höhnel.)

1 to 3, beard-hairs; 4 to 6, wool-hairs; *gs*, near the end of hair; *gm*, middle of hair; *gb*, near base of hair; *wm*, middle of wool-hair; *ws*, point of wool-hair; *f*, fibrous fissures; *m*, medullary cells; *z*, serrated edge of medulla; *r*, tooth-like formation of epidermal scales.

ure from 34 to 120 μ in diameter, and from 1 to 2 cm. in length. The medullary canal is filled with several series of cells, quadrangular in shape and with thin walls. They are also arranged

in a very regular manner. By careful observation spiral stria-
tions may be noticed on the finer fibres. The epidermal scales
are very thick and their forward edges terminate in a sharp point
(see Fig. 30). Each scale is placed cornucopia-like into the next
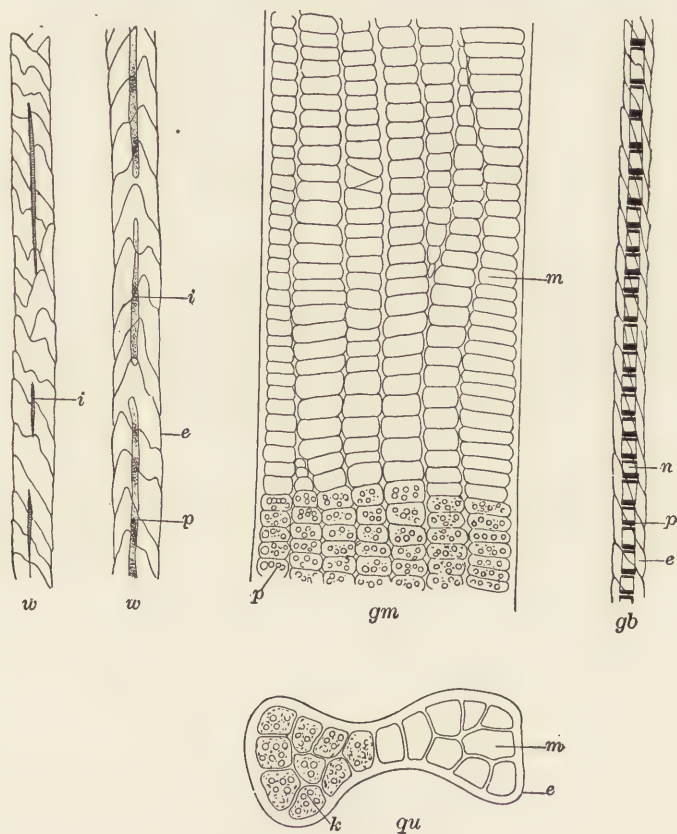
FIG. 30.—Hair of Rabbit. (×340.) (Höhnel.)

w, wool-hairs; *gm*, middle and broadest part of beard-hair; *qu*, cross-section of
beard-hair; *gb*, base of beard-hair; *e*, cusp-like scales; *i*, medullary islands;
m, *n*, medullary cells with granular contents; *p*, *k*, pigment plate-like cells.

lower one, and is drawn out into 1 to 3 large waves. At the base
of the fibre the medulla consists of a single row of cells, above
the middle this increases to 2 to 4 rows, and further along the fibre
the number of rows of cells increases up to 8, when the hair

becomes very wide.   Like most pelt-hairs, the fibres are somewhat
flattened at the base, and quite so at their broadest part.   The
cortical layer is only apparent towards the point where the medulla
ceases.   The fine wool-hairs of the rabbit are much thinner than
the above, the greatest thickness being about 20 μ.   Otherwise
they correspond in structure to that part of the above fibre near
the base.

CHAPTER VI.

SILK: ITS ORIGIN AND CULTIVATION.

1. General Considerations.—The silk fibre consists of a continuous thread which is spun by the silkworm. The worm winds the fibre around itself in the form of an enveloping cocoon before it passes into the chrysalis or pupal state. The cocoon is ovoid in shape and is composed of one continuous fibre, which varies in length from 350 to 1200 meters (400 to 1300 yards), and has an average diameter of 0.018 mm. In the raw state the fibre consists of a double thread cemented together by an enveloping layer of silk-glue, and is yellowish and translucent in appearance. When boiled off or scoured these double threads are separated, and the silk then appears as a single lustrous almost white fibre. Unlike both wool and cotton, silk is not cellular in structure, and is apparently a continuous filament devoid of structure. Höhnel, however, believes that the silk fibre is not so simple in structure as would at first be believed. The surface of the fibre frequently shows faint striations, which may be rendered more apparent by treatment with chromic acid. Also by saturating the silk with moderately concentrated sulphuric acid and drying, then heating to 80° to 100° C., the fibre will be disintegrated into small filaments, which would seem to indicate that it was made up of a number of minute fibrils firmly held together.

2. The Silkworm.—The silkworm is a species of caterpillar, and though there are quite a number of the latter which possess silk-producing organs, the number which secrete a sufficient quantity of the silk substance to render them of commercial importance is rather limited. The true silkworms all belong to the general class *Lepidoptera*, or scale-winged insects, and more specifically to the

genus *Bombyx*.   The principal species is the *Bombyx mori*, or mul-
berry silkworm, which produces by far the major portion of the
silk that comes into trade.   The silk industry appears to have had
its origin in China, and historically it dates back to about 2700
years B.C.   In its early history it is said that the art of cultivat-
ing the silkworm and preparing the fibre for use was a strictly
guarded secret known only to the royal family.   Gradually, how-
ever, it spread through other circles and soon became an important
industry distributed universally throughout China.   The Chinese
monopolized the art for over three thousand years, but during
the early period of the Christian era the cultivation of the silk-
worm (or sericulture) was introduced into Japan.   It also gradually
spread throughout central Asia, thence to Persia and Turkey.
In the eighth century the Arabs acquired a knowledge of the
silk industry, which soon spread through all the countries in-
fluenced by the Moorish rule, including Spain, Sicily, and the
African coast.   In the twelfth century we find sericulture practised
in Italy, where it slowly developed to a national industry.   In
France sericulture appears to have been introduced about the
thirteenth century, but it was not until the reign of Louis XIV.
that it assumed any degree of importance.   In more recent
times experiments have been made on the cultivation of the
silkworm in almost every civilized country.*

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   * Mr. Samuel Whitmarsh, about 1838, appears to have been the first to
attempt sericulture in America.   He cultivated the *Motus multicaulis* in Penn-
sylvania, but the experiment proved to be a failure.   In later years there have
been many attempts to introduce the industry of sericulture into the United States,
and it has been satisfactorily demonstrated that good silk can be raised in this
country, more especially in the Southern States.   The failure of the industry has
not been due to lack of proper climatic conditions, but simply to the high cost
of labor as compared with Oriental labor.   With respect to the amount of raw
material consumed, the United States stands first among the silk manufacturing
countries of the world, though in the value of its manufactures it ranks second.
   For the calendar year of 1905, there were imported into the United States
raw silk, or as reeled from the cocoon, 15,514,718 pounds, valued at $54,812,294.
In addition to this waste silk was imported to the amount of nearly four million
pounds.   In amount of value the imports for 1905 were about the same as for
1904, and considerably in excess of that for 1903.   Of silk manufactures, there
were imported for 1905, $33,591,144 in value, consisting chiefly, or nearly fifty
per cent., of dress and piece goods.   In this was included over three million dol-

According to the number of the generations they produce in a year, the *Bombyx mori* are divided into two classes: the members of the one reproduce themselves several times annually, and are termed *polyvoltine;* their cocoons are small and coarse. The other worms have only one generation in a year, and hence are termed *annual.* The cocoons of the latter are much superior
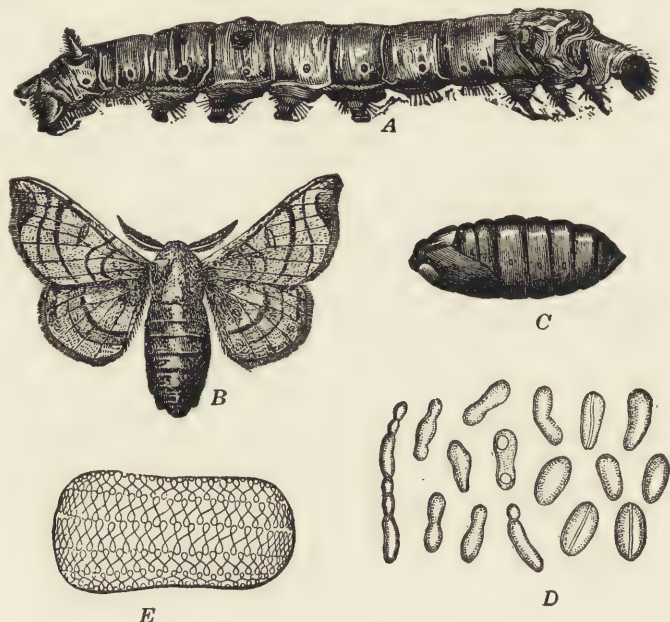

FIG. 31.—Showing Different Stages in Growth of Silkworm.
A, silkworm in fifth period, full size; *B*, moth or butterfly; *C*, chrysalis, or pupa; *D*, eggs of moth; *E*, diagram showing cocoon and method of winding.

to those of the former. The cultivation of the silkworm starts with the proper care and disposition of the eggs.* With the

lars' worth of spun silk. According to this, about one-fourth of the value of the American consumption of silk manufactures was imported, and about one-fifth of the value of silk dress goods consumed in this country was of foreign make.

* There are two kinds of silkworm culture: one for production and one for breeding. The object in the first case is to get the greatest yield of cocoons, and with a little training may be carried on by any one of ordinary intelligence.

The object in culture for breeding is to secure eggs free from hereditary taint of disease, and experts only can be depended on for this culture. Besides

annual worms there elapse about ten months between the time the eggs are laid and their hatching. The hatching only takes place after the eggs have been exposed to the cold for some time and are subsequently subjected to the influence of heat. When the eggs are laid by the silk-moth they are received on cloths, to which they stick by virtue of a gummy substance which encloses them. For the first few days they are hung up in a room, the air of which is kept at a certain degree of humidity—about semi-saturation. Then comes a period of hibernation, during which the eggs are kept in a cool place; at present artificial refrigeration
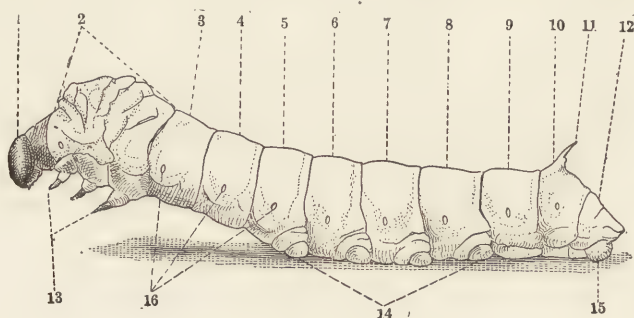
FIG. 32.—The Silkworm.

1, head; 2–10, 12, rings; 11, horn; 13, articulated legs; 14, abdominal or false legs; 15, false legs on last ring.

is resorted to in many establishments. The period of hibernation lasts about six months. After this comes the period of incubation, in which the embryo is gradually developed into a worm and the egg is hatched. The hatching usually takes place in heated compartments, in which the temperature is carefully regulated. The period of incubation occupies about thirty days, though this time has been shortened considerably by certain artifices, such as the action of electric discharges. Twenty-five grams of eggs will yield about 36,000 worms on hatching. The cater-pillar, on first making its appearance, is about 3 mm. long, and

a careful physiological examination throughout the rearing, the body of the mother moth is microscopically tested after death, and her eggs are not retained if signs of disease are discovered. In this way the birth of healthy worms is insured. Pasteur first applied this method of selecting silkworm eggs, and thus checked the plague (pebrine) which was rapidly destroying silkworm culture in Europe. (*Silkworm Culture*, Bull. U. S. Dept. Agric.)

weighs approximately 0.0005 gram. Its growth and development
proceeds with extraordinary rapidity, and during its short exist-
ence it undergoes a number of very curious transformations.
Under normal conditions there elapse thirty-three to thirty-four
days between the time of the hatching of the egg and the com-
mencement of the spinning of the cocoon. During this time
the worm sheds its skin four times, and these periods of moulting
divide the life-history of the worm into five periods.* Almost
immediately after being hatched the worms commence to devour
mulberry leaves with great avidity, and continue to eat throughout
the five periods, though, when about to shed their skins, they stop
eating for a time and become motionless. The size and weight
of the caterpillars increase with remarkable rapidity; during
the fifth period they reach their greatest development, measur-
ing from 8 to 9 cm. in length (see Fig. 32) and weighing from
4 to 5 grams, and after thus maturing they begin to diminish in
weight. The following table by Vignon shows the relative weights
of the silkworm during the different stages of its existence.
The figures refer to the weight of 36,000 worms.

	Grams.
Eggs...	25
Worms (36,000).....................................	17
First period (5 to 6 days).............................	255
Second period (4 to 5 days)...........................	1,598
Third period (6 to 7 days)............................	6,800
Fourth period (7 to 8 days)...........................	27,676
Fifth period (11 to 12 days)..........................	161,500
At maturity...	131,920
Cocoons..	76,250
Chrysalis alone......................................	66,300
Butterflies, half of each sex.	99,865

Thus we see that in less than forty days the weight of the
silkworm increases almost 10,000 times.

When the worm has reached the limit of its growth, it ceases

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* The length of time occupied in these different ages approximates as follows:
    1st, from birth to first moult, 5 to 6 days.
    2d, from first to second moult, 4 days.
    3d, from second to third moult, 4 to 5 days.
    4th, from third to fourth moult, 5 to 7 days.
    5th, from fourth moult to maturity, 7 to 12 days.

to eat, and commences to diminish in size and weight. The time is now ready for the spinning of its cocoon; the worm perches on the twigs so disposed to receive it and exudes a viscous fluid from the two glands in its body wherein the silk secretion is formed. The liquid flows through two channels in the head of the worm into a common exit-tube, where also flows the secretion of two other symmetrically situated glands which cements the two threads together. Consequently, the thread of raw silk is produced by four glands in the worm; the two back ones secrete the fibroin which gives the double silk fibre, while the two front glands secrete the silk-glue or sericin which serves as an
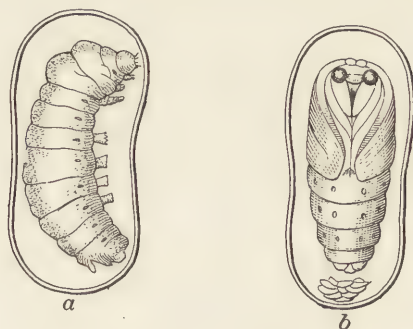
FIG. 33.—Cross-section of Silk-cocoon.

a, silkworm at completion of cocoon; b, after development of chrysalis with cast-off skin of larva beneath.

integument and cementing substance.* On emerging from the spinneret in the head of the worm the fibre coagulates on contact with the air.†

The worm weaves this thread around itself, layer after layer, until the cocoon or shell is gradually built up.‡ It requires about

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* According to Bolley the glands in the silkworm which secrete the fibre-producing liquids contain only glutinous, semi-fluid fibroin without admixture with sericin, the latter compound being a product of the subsequent oxidation of the fibroin by the air.

† The contents of the glands of the silkworm have been the subject of study in a peculiar manner by Chappe. He triturated the glutinous matter with about one-third its weight of water, and thus obtained a liquid from which he was enabled to blow variously shaped vessels of a very permanent character. (*Ann. de Chim.*, vol. 11, p. 113.)

‡ First a net is formed to hold the cocoon which is to be spun, then the regu-

three days for the completion of the cocoon.   After finishing the
winding of its cocoon, the enclosed silkworm undergoes a remark-
able transformation, passing from the form of a caterpillar into
an inert chrysalis or pupa, from which condition it rapidly devel-
ops into a butterfly, which then cuts an opening through the
cocoon and flies away.*   As the integrity of the cocoon-thread
would be destroyed by the escape of the butterfly and hence lose
much of its value, it is desirable that the development of the chrys-
alis be stopped before it proceeds too far, and this is accomplished

FIG. 34.—The Silk-moth.   *a*, male; *b*, female.

by killing it by a heat of from 70° to 80° C. or by live steam.
The cocoons at this stage weigh from 1.25 to 2.5 grams each,

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lar spinning begins and the form of the cocoon is designed.   It is calculated that
with its head alone the silkworm makes 69 movements every minute, describ-
ing arcs of circles, crossed in the form of the figure 8.   Meanwhile the web grows
closer and the veil thickens, and in about 72 hours the worm is completely shut
up in its cocoon, which serves it as a protective covering. (*Silkworm Culture*,
Bull. U. S. Dept. Agric.)

  * The worm in spinning the cocoon leaves one end less dense, so that the
threads open freely to permit the egress of the moth.   By the aid of an alkaline
fluid the moth softens and parts the threads and liberates itself. (*Silkworm
Culture.*)

and of this 15 to 16 per cent. is silk fibre.*   However, only 8 to
10 per cent. is available for silk filaments, the remainder, 6 to
7 per cent., constituting waste and broken threads, and is utilized
for spun silk.†   As to the thickness of the filaments of silk in
the cocoon, Haberlandt furnishes the following data.

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* The proportion of silk in a cocoon varies according to the race and also to
the regimen to which the worm has been subjected.   The average normal cocoon at
the time it is sold is thus composed:

	Per Cent.
Water.	68.2
Silk.	14.3
Web and veil.	.7
Chrysalis.	16.8

(*Silkworm Culture.*)

† There are several different varieties of waste silk, as follows:

1. The refuse obtained in raising the silkworm, called watt silk in commerce.
Owing to the scientific methods of silk-culture in Europe, the amount obtained
from this source is very small.   China, however, exports a large amount yearly.
This material contains about 35 per cent. of pure silk, and is the poorest grade
of waste silk on account of its irregularity.

2. The irregularly spun and tangled silk on the outside of the cocoon, called
floss silk or frisons.   It comprises from 25 to 30 per cent. of the entire cocoon,
and is valuable owing to its purity and fine quality.

3. The residue of the cocoon after reeling; this forms an inner parchment-like
skin, and in commerce goes under the name of ricotti, wadding, neri, galettame,
basinetto, etc.

4. Cocoons imperfect from various causes, such as being punctured by the
worms, becoming spotted by pupa breaking, etc.   These are known as cocons,
perces, piques, tarmate, rugginose, etc.   It forms a valuable material for floss-
silk spinning.

5. Double cocoons, which, in spite of the difficulty in reeling, were formerly
used for special purposes.   Now such cocoons are converted into waste which
is know as strussa.

6. Waste obtained in reeling the cocoons, known as frisonnets.

7. A great variety of wild silks, which, for the most part, cannot be reeled,
and are, therefore, first converted into waste.   A large quantity of wild silk,
even though it can be reeled, is torn up for waste.

8. Waste made by reeling, spooling, and other processes of working silk.

Silk shoddy resembles wool shoddy in origin, consisting of recovered fibres
from manufactured silk goods.   It nearly always contains isolated fibres of both
wool and cotton, and frequently mixtures of different kinds of silk.   There may
also occur boiled-off, soupled, and raw silk, and mixtures of organzine and spun
silk.   Different colors are also usually present.   The fibres, as a rule, are quite
short, being about a centimeter in length.   Due to these components, silk shoddy
is comparatively easy to recognize under the microscope.

Species.	Exterior Layer of Cocoon.	Middle Layer.	Interior. Layer.
Yellow Milanais..............	0.030 mm.	0.040 mm.	0.025 mm.
Yellow French..............	0.025 "	0.035 "	0.025 "
Green Japan................	0.030 "	0.040 "	0.020 "
White Japan................	0.020 "	0.030 "	0.017 "
Bivoltin worms.............	0.025 "	0.035 "	0.020 "

The double silk fibre as it exists in the cocoon is known as the *bave,* and the single filaments are called *brins.*

The size of the single silk filament as it comes from the cocoon averages $2\frac{1}{4}$ deniers.* The following table gives the approximate size of filaments of mulberry silk from different countries

Country.	Weight of 500 Meters.	
	In Deniers.	In Milligrams.
Spain...........................	3.0	163
France..........................	2.6	138
Italy............................	2.4	128
Syria...........................	2.4	128
Caucasus........................	2.3	125
Brousse.........................	2.2	117
Japan...........................	2.1	113
China...........................	2.0	108
Bengal..........................	1.2	64

3. Diseases of the Silkworm.—The silkworm is particularly liable to contract various diseases, which become more or less epidemic in character. In the early history of sericulture in Europe the industry was frequently threatened with almost total destruction by the widespread ravages of certain diseases of the silkworm. The French chemist Pasteur devoted much attention to this subject and succeeded in devising means of avoiding or preventing almost all such diseases. The principal diseases of the silkworm are the following.

(*a*) *Pebrine.*† Worms afflicted with this disease develop

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* See page 112.

† Between 1833 and 1865 the annual crop of cocoons in France was reduced by pebrine from 57,200,000 lbs. to 8,800,000 lbs. It was first noticed in epidemic form in France in 1845, but since then has spread throughout Asia Minor and the Orient.

slowly, irregularly, and very unequally. Black spots are the most marked outward characteristics: the internal signs are oval corpuscles visible only under the microscope. There appears to be no remedy for this disease, but Pasteur found it could be prevented by a microscopical selection of the eggs, and at the present day it causes but little trouble among silk-growers.

(*b*) *Flacherie* (or flaccidity) is at present the most dreaded disease among European silkworms. It usually affects the worm after the fourth moult, or even while spinning, Without apparent cause the worms begin to languish and shortly die.
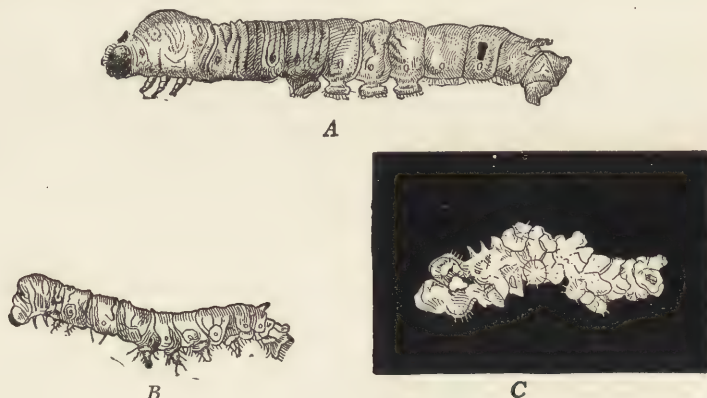
FIG. 35.—Diseased Silkworms.

A, worm afflicted with flacherie; *B*, worm emaciated by gattine; *C*, calcinated worm. ·(After *Silkworm Culture*.)

After death they turn black in color and emit a disagreeable odor. Flacherie is apparently a form of indigestion, and may be induced by micro-organisms in the intestinal canal of the worm. Contagion is usually prevented by dipping the eggs in a solution of copper sulphate, and as the micro-organisms causing flacherie persist alive from year to year, very careful fumigation must be instituted whenever this disease develops.

(*c*) *Gattine* shows itself externally by indifference of the worm to food, torpor, and generally emaciation. It usually affects the worm in the early ages, though it is sometimes associated with flacherie. The best preventive against both flacherie and gattine is a careful selection of healthy eggs.

(*d*) *Calcino* (or muscardine) at first does not exhibit any external characteristics, but the vitality of the worm is slowly impaired and it feeds and moves but slowly. The body becomes reddish in color, and gradually contracts and loses its elasticity, and the worm usually dies 20–30 hours after the first symptoms of the disease. The dead body dries up and becomes covered with a white chalk-like efflorescence. The disease is caused by a minute fungus,* the spores of which take root in the body of the worm, and finally fill the entire body. Calcino is the most contagious of the silkworm diseases, and its appearance should be promptly checked by careful fumigation with burning sulphur.

(*e*) *Grasserie* shows itself by the worms becoming restless, bloated, and yellow in color, and when punctured they exude a fetid matter filled with minute granular crystals. The disease is not caused by microbes, hence is neither contagious nor hereditary. Its chief cause is mismanagement of the worms at moulting periods and uneven feeding.

4. Wild Silks.—Besides the *Bombyx mori,* or mulberry silkworm, there are other associated varieties of caterpillars which also produce silk in sufficient quantity to be of considerable commercial importance. Due to the fact that such silkworms are not capable of being domesticated and artificially cultivated like the mulberry worms, the silk obtained from them is called wild silk. Of this latter there are several commercial varieties, of which the most important are here given.†

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* There are two varieties of this fungus: *Botrytis bassiana* and *B. tevella.* The white chalk-like appearance of the dead worm is caused by the branches of the fungus fructifying on the surface, and the fruit bursting envelops the worm with innumerable spores resembling a white powder.

† Attention has recently been drawn to the possibility of obtaining silk from a species of spider chiefly found in Madagascar. This spider is known as *Nephila Madagascariensis.* The egg-receptacle is a silky cocoon about one inch in diameter and of a yellow color, but turning white after several months' exposure to the air. The female spider alone produces the silk and is about two and a half inches long. The silk is reeled off from the spider five or six times in the course of a month, after which it dies, having yielded about 4,000 yards. The reeling is done by native girls; about one dozen spiders are locked in a frame in such a manner that on one side protrudes the abdomen, while on the other side the head, thorax, and legs are free. The ends of their webs are drawn out, collected into one thread, which is passed over a metal hook, and the reel is set in motion

Antheræa yama-mai, a native of Japan, is a green-colored caterpillar which feeds on oak-leaves. Its cocoon is large and of a bright greenish color. The silk bears a close resemblance to that of the *Bombyx mori*, but is not as readily dyed and bleached as the latter.

Antheræa pernyi is a native of China; besides growing wild, it has been domesticated to some extent. This worm also feeds on oak-leaves, but is of a yellow color. Its cocoon is quite large, averaging over 4 cm. in length, and is of a yellowish to a brown color.

Antheræa assama is a native of India; it gives a large cocoon over 45 mm. in length.

Antheræa mylitta is another Indian variety, and furnishes the so-called *tussah* silk, though this term has also been applied in a general manner to all varieties of wild silk. The worms feed on the leaves of the castor-oil plant, and give very large cocoons, reaching 50 mm. in length and 30 mm. in diameter. The fibre is much longer than from the cocoon of the *B. mori*, and varies from 600 to 2000 yards in length. The color of tussah silk varies from a gray to a deep brown.

Another variety of silkworm which is to be found both in Asia and America is the *Attacus ricini*. It gives a very white and good quality silk, the production and value of which is increasing every year. It is known as Eria silk. The structure of the fibre much resembles that of tussah silk. A species of this class, known as *Attacus atlas*, is perhaps the largest moth known; it spins open cocoons and gives the so-called Fagara, or Ailanthus, silk.

Wild silks are much more difficult to unwind from the cocoons than that of the mulberry silkworm. Wild silk is also much darker in color. As the individual filaments are much coarser than

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by a pedal. The extraction of the web does not apparently inconvenience the spider. The cost of the material is high, as 55,000 yards of 19 strands thickness weighs only 386 grains, and one pound of the silk is worth $40. At the Paris Exposition of 1900, a fabric was shown, 18 yards long by 18 inches wide, containing 100,000 yards of spun thread of 24 strands, the product of 25,000 spiders. It was golden yellow in color. Spinning spiders are also known in Paraguay, Venezuela, and other countries. (See *Jour. Soc. Arts*, vol. 53, p. 620.)

those of mulberry silk the former, as a rule, have greater strength, but on reduction to a basis of equal diameters, the filaments of mulberry silk are somewhat stronger, and are much more difficult to dye and bleach.

Tussah (or tussur) silk (as well as other wild silks) is chiefly employed for making pile-fabrics, such as velvet, plush, and imitation sealskin.

5. The Microscopical and Physical Properties of Silk.—Under the microscope raw silk exhibits an appearance which readily distinguishes it from other textile fibres. It is seen as a smooth structureless filament, very regular in diameter and very transparent. The two brins in the bave of raw silk give beautiful colors with polarized light when examined microscopically. The sericin coating, however, appears to have no such action. The latter, being hard and brittle, on bending develops transverse cracks which are very apparent under the microscope.

The fibre of *Bombyx mori* is only rarely striated longitudinally, and when such striations do appear they always run parallel to the axis of the fibre. When treated with dilute chromic acid very fine striations are caused to appear. Wild silks often show fibres which are twisted on their axes, and the layer of gum is usually more or less granular. *Antheræa mylitta* shows rather frequent oblique striations, and does not exhibit much play of color with polarized light. This latter characteristic is also true of *Antheræa yama-mai.* The other silks give nice colors with polarized light. Silk fibres are colored a deep red with alloxanthin; fuchsin also gives a red color. On treatment with sugar and sulphuric acid, silk is first colored a rose-red and then dissolves; hydrochloric acid gives a violet color and then dissolves the fibre. Iodin colors the fibres yellow to reddish brown.

Carded silk, which has been worked up from imperfect cocoons, etc., can usually be recognized under the microscope by the irregular and torn appearance of its external layer of gum.

The inner layers of the cocoon consist of a yellow parchment-like skin, and when examined under the microscope exhibit a matrix of sericin, in which numerous double fibres are imbedded,

usually very much flattened in cross-section (Fig. 36, *a*). These
inner layers, of course, are not capable of being reeled with the
rest of the cocoon, and are used for waste silk. The cross-
sections of the fibres from the middle portion of the cocoon, con-
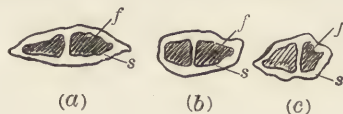
FIG. 36.—Cross-sections of Silk Fibre. (×500.)

a, from inner part of cocoon; *b*, from middle layers; *c*, from outer part; *f*, fibre
of fibroin; *s*, layer of sericin. (Micrograph by author.)

stituting the reeled silk, are much more rounded in form and
are surrounded with a thinner layer of sericin (see Fig. 36, *b*).
The fibres of the outer part of the cocoon, also utilized for waste
silk, exhibit a rather irregular cross-section (see Fig. 36, *c*).

FIG. 37.—Appearance of Raw Silk (×500) under the Microscope, showing the
Double Cocoon Filament and the Irregular Shreds of Silk-glue. (Micro-
graph by author.)

When raw silk is examined under the microscope it will be
seen that the appearance is by no means regular, owing to the

broken and torn surface of sericin which surrounds the fibre (see Fig. 37). Frequently the two filaments of fibroin are distinctly separated from one another for considerable distances, the intervening space being filled in with sericin. Occasionally the layer of sericin is seen to be entirely absent, having been removed by breaking or rubbing off. The sericin layer also shows frequent transverse f.ssures, which are merely cracks caused by the breaking of the sericin in the bending or twisting of the fibre. Creases and folds in the sericin, as well as irregular lumps, are also of frequent occurrence. All of these markings are in nowise structural, and only occur in the sericin layer. At times the fibroin fibre exhibits structural changes in places, such as attenuations; but these only occur in defective and unhealthy silk, and give rise to weak places. These are caused by the fibroin not being secreted by the gland with sufficient rapidity when the fibre is being spun by the worm.

The microscopic appearance of the wild silks is very different from that of the *Bombyx mori*. The fibres are very broad and thick, and in cross-section are very flat, and often triangular in outline. Longitudinally they show very distinct striations and peculiar flattened markings, usually running obliquely across the fibre, and in which the striations become more or less obliterated. These cross-markings are caused by the overlapping of one fibre on another before the substance of the fibre had completely hardened, in consequence of which these places are more or less flattened out (see Fig. 38). The striated appearance of wild silk is evidence that structurally the fibre is composed of minute filaments; in fact the latter may readily be isolated by maceration in cold chromic acid. According to Höhnel, these structural
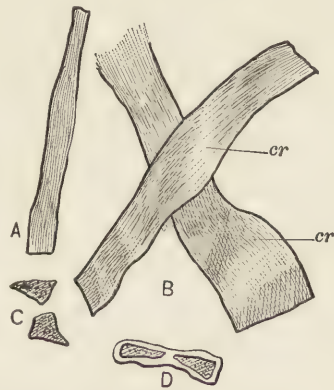
FIG. 38.—Wild Silk. (×250.) *A*, view of narrow side; *B*, view of broad side; *C*, cross-section; *D*, cross-section of double fibre; *cr*, cross-marks on fibre. (Micrograph by author.)

elements are only 0.3 to 1.5 μ in diameter; they run parallel to each other through the fibre, and are rather more dense at the outer portion of the fibre than in the inner part (see Fig. 39). Besides the fine striations on the fibres of wild silk caused by their structural filaments, there are also to be noticed a number of irregularly occurring coarser striations. These latter appear
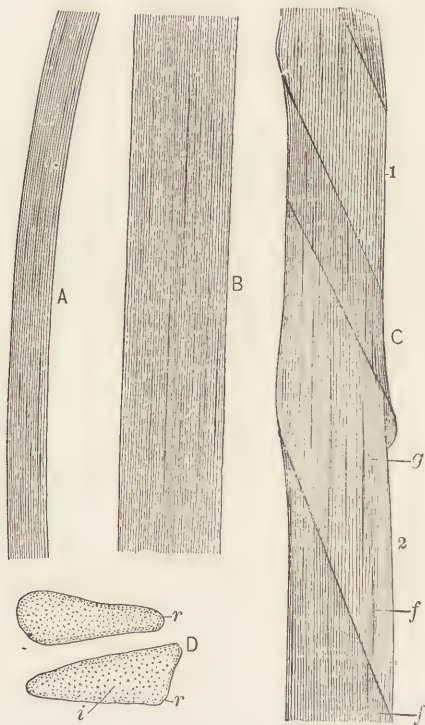
Fig. 39 —Tussah Silk.   ($\times$340.)

A, view of narrow side; *B*, view of broad side; *C*, flat surface of single fibre show-
ing two thin cross-marks at 1 and 2; *f*, air-canals; *g*, fibrillæ; *D*, cross-sec-
tions; *i*, inner layers; *r*, denser marginal layers.   (After Höhnel.)

to be due to air-canals, or spaces between the filaments of the fibre (see Fig. 40).

Höhnel is of the opinion that there is really no difference in kind between the structure of wild silk and that of cultivated silk; that is to say, the fibroin fibre of the latter is also composed

of structural filaments, only they fuse into one another in a more homogeneous manner on emerging from the fibroin glands, thus rendering it more difficult to recognize them superficially. This view is upheld somewhat by the fact that a slight striated appearance may be noticed when the silk fibre is macerated in chromic acid solution. This apparent structure of the silk fibre,
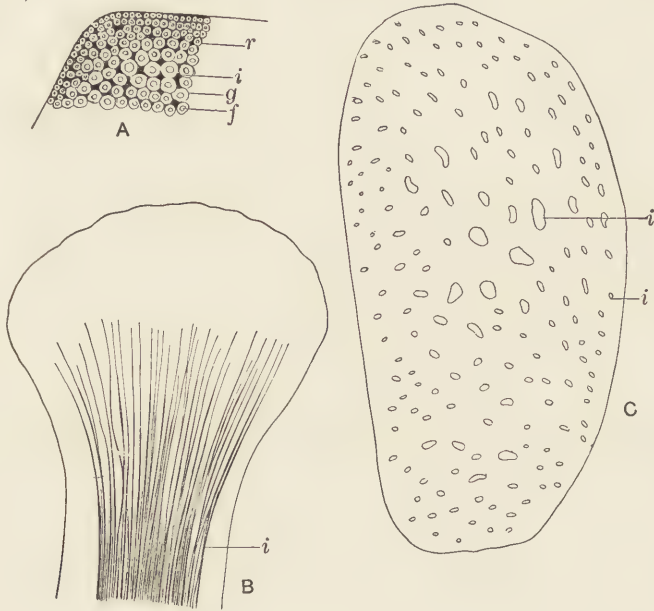
FIG. 40.—Cross-section of Wild Silk.

A, diagramatic drawing of section; *i*, air-space; *g*, ground matrix; *f*, fibrillæ; *r*, marginal layer; *B*, end of fibre of tussah silk swollen in sulphuric acid; *C*, cross-section of fibre of tussah silk swollen in sulphuric acid. (After Höhnel.)

however, may also be due to another cause. If a plastic glutinous mass (such as melted glue, for instance) be pulled out into the form of a thread and allowed to harden, it will be found to exhibit the same striated structure as the silk fibre; and this structure will be more apparent if the thread is pulled out and hardened more rapidly. The liquid fibroin in the glands of the worm is a plastic glutinous mass analogous to melted glue, and is pulled out into the form of a thread by the action of the

worm in winding its cocoon; hence it would be natural to expect a striated structure similar to that observed in the thread of glue. Thus, it is possible to account satisfactorily for the structure of the silk fibre in a perfectly natural manner without having recourse to a very doubtful organic process in the formation of the fibre, such as is supposed to be the case by Höhnel.

Silk is quite **hygroscopic,** and under favorable circumstances will absorb as much as 30 per cent. of its weight of moisture and still appear dry. It is therefore customary to determine the amount of moisture in each lot at the time of sale. This is called **conditioning** (see page 53), and is usually carried out in official laboratories. The amount of "regain" which is legally permitted is 11 per cent.; this would be equivalent to 9.91 per cent. of moisture in the silk. Boiled-off silk appears to contain somewhat less moisture than raw silk, the silk gum having a greater attraction, or power of absorbing water, than the fibre proper. The amount of moisture in boiled-off silk is usually regarded as about 8.45 per cent., which would correspond to a regain of 9.25 per cent.

Being a bad conductor of electricity, silk is readily **electrified** by friction, which circumstance at times renders it difficult to handle in the manufacturing process. The trouble can be overcome to a great extent by keeping the atmosphere moist.

The most striking physical property of silk, perhaps, is its high **lustre.** The lustre only appears after the silk has been scoured and the silk-gum removed. The lustre of silk is affected more or less by the various operations of dyeing and mordanting, and especially when the silk is heavily weighted. After dyeing, especially in the skein form, silk usually undergoes what is termed a lustring operation, which consists generally in stretching the hanks strongly by twisting, and simultaneously steaming under pressure for a few minutes. This process seems to bring back to a considerable extent the lustre of the dyed silk. Lustring, or "brightening," may also be accomplished by steeping the skeins of silk in a solution of dilute acid, such as acetic or tartaric acid, squeezing, and drying without washing. The lustre is also considerably affected by the method of dyeing and the chemicals

employed in the dye-bath; it has been found that the addition of boiled-off liquor (the soap solution of sericin obtained in the degumming of raw silk) to the dye-bath has the result of preserving the lustre of the dyed silk better than anything else, and in consequence boiled-off liquor is nearly always employed as the assistant in dyeing in preference to Glauber's salt or common salt.

Silk is also distinguished by its great **strength.** It is said that its tensile strength is almost equal to that of an iron wire of equal diameter.* The silk fibre is also very **elastic**, stretching 15 to 20 per cent. of its original length in the dry state before breaking. Degummed or boiled-off silk is somewhat lower in strength and elasticity than raw silk, the removal of the silk-gum apparently causing a decrease of 30 per cent. in the tensile strength and 45 per cent. in the elasticity. The weighting of silk also causes a decrease in its strength and elasticity.

The following table gives the diameter, elasticity, and tensile strength of the cocoon-thread of the chief varieties of silks (Wardle, *Jour. Soc. Arts*, vol. 33, p. 671).

Name of Silk.	Country.	Diameter, Ins.		Elasticity, Ins. in One Ft.		Tensile Strength, Drams.		Size of Cocoon Ins.
		Outer Fibres.	Inner Fibres.	Outer Fibres.	Inner Fibres.	Outer Fibres.	Inner Fibres.	
Bombyx mori.	China	.00052	.00071	1.3	1.9	1.6	2.6	1.1×0.5
Bombyx mori.	Italy	.00053	.00068	1.2	1.9	1.9	2.6	1.2×0.6
Bombyx mori.	Japan	.00057	.00069	1.2	1.4	2.0	3.1	1.1×0.6
Bombyx fortunatus.	Bengal	.00045	.00051	1.8	2.3	1.6	2.8	1.2×0.5
Bombyx textor. .. .	India	.00042	.00047	1.5	1.9	1.4	2.6	1.2×1.5
Antheræa mylitta. ..	India	.00161	.00172	1.9	2.7	6.6	7.8	1.5×0.8
Attacus ricini.	India	.00085	.00093	1.7	2.0	1.5	3.0	1.5×0.8
Attacus cynthia . . .	India	.00083	.00097	2.6	2.9	2.4	3.5	1.8×0.8
Antheræa assama. . .	India	.00128	.00125	2.4	2.9	2.8	4.8	1.8×1.0
Attacus selene.	India	.00100	.00109	2.0	2.8	2.4	4.0	3.0×1.2
Attacus atlas.	India	.00102	.00111	1.9	2.8	2.1	4.1	3.5×0.8
Antheræa yama-mai.	Japan	.00088	.00096	2.0	4.0	6.8	7.5	1.5×0.8
Cricula trifenestrata.	India	. . . . .	.00120	. . . . .	. . . . .	. . . . .	. . . . .	2.0×0.8
Antheræa pernyi. . . .	China	.00118	.00138	2.0	2.7	3.2	5.8	1.6×0.8

The **density** of silk in the raw state is 1.30 to 1.37, while boiled-off silk has a density of 1.25.

* The breaking-strain of raw silk is equivalent to about 64,000 lbs. per sq. in, or nearly o e-third that of the best iron wire.

Another property of silk, and one which is peculiar to this fibre, is what is termed its **scroop**; this refers to the crackling sound emitted when the fibre is squeezed or pressed. To this property is due the well-known rustle of silken fabrics. The scroop of silk does not appear to be an inherent property of the fibre itself, but is acquired when the silk is worked in a bath of dilute acid (acetic or tartaric) and dried without washing. A satisfactory explanation to account for the scroop has not yet been given; it is probably due to the acid hardening the surface of the fibre. Mercerized cotton can also be given a somewhat similar scroop by such a treatment with dilute acetic acid. Wool, under certain conditions of treatment, in some degree can also be given this silk-like scroop, as, for instance, when it is treated with chloride of lime solutions or with strong caustic alkalies.

6. Silk-reeling.—The silk fibre, as it appears in trade for use in the manufacture of textiles, is obtained by unreeling the cocoon. After the cocoons have been spun by the silkworms they are heated in an oven for several hours at a temperature of from $60°$ to $70°$ C., for the purpose of killing the pupa or chrysalis contained within, before the latter shall have developed sufficiently to begin cutting its way through the envelope and thus destroy the continuity of the cocoon-thread   Another method of operation is to steam the cocoons; this requires only a few minutes to kill the pupa, and is said to be preferable to the oven-heating, as it causes less damage to the fibre, and at the same time considerably softens the silk-glue, thus rendering the subsequent process more easy. After the killing of the worms is accomplished, the cocoons are sorted into several grades, according to size, color, extent of damage, etc., after which they are ready for reeling. This is entirely a mechanical process requiring much skill. The cocoons are soaked in warm water until the silk-glue is softened; the operator seizes the loose ends of several fibres together on a small brush and passes them through the porcelain guides of a reel, where they are twisted together to form threads of sufficient size for weaving. Two threads are formed simultaneously on each reel, and are made to cross and rub against each other to remove twists in the fibre (see Fig. 41), and also to rub the softened

silk-glue coverings together in order that the fibres may become firmly cemented and form a uniform thread. The product so obtained is termed **raw silk** or *grège;* **floss silk**, which is used for making **spun silk**, is the term applied to the waste resulting from short and tangled fibres from the exterior of the cocoon, and from those cocoons which have been broken by the moth in escaping. Raw silk is classified into two grades: (*a*) *Organzine* silk, which is made from the best-selected cocoons, and is
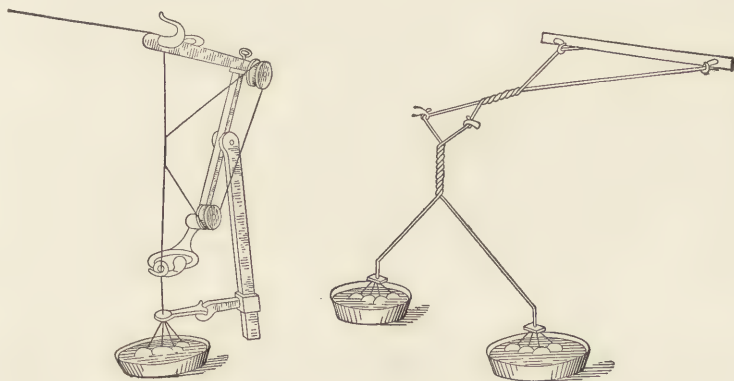
Fig. 41.—Showing Methods of Reeling the Silk Fibre from the Cocoon.

chiefly used for warps on account of its greater strength; and (*b*) *Tram* silk, which is made from the poorer quality cocoons, and is mostly employed for filling. Floss or waste silk cannot be reeled, so the cocoon-threads are scoured in a solution of soda and soap,* and afterwards combed and carded in special machines. The better quality and longer fibre is worked up into what is

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* There are two ways in which waste silk may be degummed for spinning: it may either be *boiled off* or *chapped*. The former is usually adopted where all the gum is to be removed, and is carried out by tying the silk up in bags and boiling in a soap solution. In the second method the gum is loosened by a process of fermentation and only a portion of the gum is removed according to requirements. The process is carried to such perfection that as much as 15 per cent. or as little as 2 per cent. of the gum may be removed. In chapping, the waste silk is piled in a heap in a damp, warm place, and kept constantly moist; the gum soon begins to ferment and soften; by continual turning of the pile all portions of the heap are properly softened, but the process takes several days. Another process is to place the silk in cages and immerse in water for several days.

known as *florette* silk, while the shorter fibres are carded and spun into *bourette* silk.*   Floss silk is also known as *chappe* or *échappe* silk.†

7. **Determination of the Size of Silk Yarns.**—The fineness or size of the silk thread is expressed by a number known as *titre* (in French) or *titolo* (in Italian); this gives the number of units of certain weight (denier = 53.13 mgms.) a skein of certain length will weigh.   Several different standards are in use in Europe at the present time, among which are the following:

	Weight in Grams.	Length in Metres.
Denier (*legale*)	0.05	450
Denier (*milano*)	0.051	476
Denier (*turino*)	0.0534	476
Old denier (*Lyonese*)	0.0531	476
New denier (*Lyonese*)	0.0531	500
Denier (international)	0.05	500

* *Silk wadding* is produced from the waste left after bourette spinning.

† According to the composition and twist of the threads, silk is classified into the following:

(1) *Organzine* (*warp* or *Orsey* silk); from 3 to 8 cocoon threads are lightly twisted together with a right-hand twist, so that there are from 60 to 80 turns per cm., and 2 to 3 such threads are twisted together left-handed to form double or threefold organzine.

(2) *Tram* or *weft* silk; characterized by a much lower degree of twist; the individual threads consisting of 3 to 12 cocoon-threads undergo no preliminary twist, and 2 or 3 of these are united by loose twisting, so that the thread is softer and flatter than organzine.

(3) *Marabout* silk; used for making crape, 2 to 3 threads being united without any preliminary twisting, then dyed without scouring and strongly twisted; a hard twist and stiffness are characteristic of this silk.

(4) "*Soie Ondee*"; prepared by doubling a coarse and a fine thread; it is mostly used for making gauze, and gives a moire or watered appearance.

(5) *Cordonnet;* 4 to 8 twisted threads are combined by a loose left twist, and 3 of the threads thus formed are united by a right-handed twist; this silk is mostly used for selvages, braiding, crocheting, knitting, etc.

(6) *Sewing* silk; made from raw silk of 3 to 24 cocoon-threads, 2, 4, or 6 of which are united by twisting.

(7) *Embroidery* silk; consists of a number of simple untwisted threads united by a slight twisting.

(8) *Poil* or *single* silk; a raw silk thread formed by twisting 8 to 10 cocoon-threads and employed for making gold and silver tinsel.   (Herzfeld, *Yarns and Textile Fabrics*, p. 89.)

The titre is usually expressed in the form of a fraction, representing limits of variation, as all skeins are not of absolutely the same size. A silk marked 18/20, for instance, would mean that it varied from 18 to 20 deniers.

The international denier may, perhaps, be more conveniently defined as being the weight (in grams) of 10,000 metres. The basis for the sizing of thrown silk in England and the United States is the weight in *drams* of 1,000 yards. To convert this measure into deniers, it is necessary to multiply by the factor 33.36. For example, if 1,000 yards of silk weigh 3 drams, it would be equivalent to $33.36 \times 3 = 100.08$ deniers. In France the size of the silk is usually expressed in terms of the old denier, which was the weight in deniers of 400 French ells. The latter length is equivalent to 476 metres, and the denier is equal to 0.05313 gram.* Hence, to obtain the size in deniers according to this system, multiply the weight in grams of 476 metres by the factor 18.82 $(= 1 \div 0.05313)$. For example, if 476 metres of silk weigh 5 grams, this would be equivalent to $5 \times 18.82 = 94.1$ deniers. To obtain the deniers under the new measure, the weight in grams of 500 metres is multiplied by the factor of 18.82. The *legal measure* in France of the size of silk is represented by the weight in grams of 500 metres, but it is probably more usual to express the size in terms of deniers. To convert the new denier into the old denier, multiply by the factor 0.952 $(= \frac{476}{500})$. The deniers on the *old system* may be converted into the *international measure* (based on a weight of 0.05 gram for a length of 500 metres) by multiplying by the factor 1.116; and, inversely, the international denier may be converted into the old system denier by multiplying by the factor 0.896.

The following tables show the relations between the different measures of the French scale:

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* The denier is supposed to be derived from the weight of a Roman coin of small value called *denarius*. The abbreviation for pence (*d*) in the English monetary system is derived also from this word.

Legal Titre.	New Denier.	Old Denier.	Internat. Denier.	Legal Titre.	New Denier.	Old Denier.	Internat. Denier.
Weight of 500 Metres in Grams.	Weight of 500 Metres in Deniers.	Weight of 476 Metres in Deniers.	Weight of 10,000 Metres in Grams.	Weight of 500 Metres in Grams.	Weight of 500 Metres in Deniers.	Weight of 476 Metres in Deniers.	Weight of 10,000 Metres in Grams.
0.1	1.88	1.78	2	5.0	94.10	89.58	100
0.2	3.76	3.58	4	5.1	95.99	91.38	102
0.3	5.64	5.36	6	5.2	97.87	93.17	104
0.4	7.52	7.16	8	5.3	99.75	94.96	106
0.5	9.41	8.95	10	5.4	101.63	96.75	108
0.6	11.29	10.73	12	5.5	103.51	98.54	110
0.7	13.17	12.53	14	5.6	105.40	100.33	112
0.8	15.05	14.32	16	5.7	107.28	102.12	114
0.9	16.93	16.11	18	5.8	109.16	103.92	116
1.0	18.82	17.91	20	5.9	111.04	105.71	118
1.1	20.70	19.70	22	6.0	112.93	107.50	120
1.2	22.58	21.49	24	6.1	114.81	109.29	122
1.3	24.46	23.28	26	6.2	116.69	111.08	124
1.4	26.35	25.08	28	6.3	118.57	112.87	126
1.5	28.23	27.87	30	6.4	120.45	114.66	128
1.6	30.11	28.66	32	6.5	122.34	116.46	130
1.7	31.99	30.45	34	6.6	124.22	118.25	132
1.8	33.87	32.24	36	6.7	126.10	120.04	134
1.9	35.76	34.04	38	6.8	127.98	121.83	136
2.0	37.64	35.83	40	6.9	129.87	123.63	138
2.1	39.52	37.62	42	7.0	131.75	125.42	140
2.2	41.40	39.41	44	7.1	133.63	127.21	142
2.3	43.29	41.20	46	7.2	135.51	129.00	144
2.4	45.17	43.00	48	7.3	137.39	130.80	146
2.5	47.05	44.78	50	7.4	139.28	132.59	148
2.6	48.93	46.57	52	7.5	141.16	134.39	150
2.7	50.81	48.57	54	7.6	143.04	136.17	152
2.8	52.70	50.16	56	7.7	144.92	137.96	154
2.9	54.58	51.95	58	7.8	146.80	139.70	156
3.0	56.46	53.74	60	7.9	148.69	141.56	158
3.1	58.34	55.54	62	8.0	150.57	143.34	160
3.2	60.22	57.33	64	8.1	152.45	145.13	162
3.3	62.11	59.12	66	8.2	154.33	146.92	164
3.4	63.99	60.91	68	8.3	156.22	148.71	166
3.5	65.87	62.70	70	8.4	158.10	150.50	168
3.6	67.75	64.49	72	8.5	159.98	152.30	170
3.7	69.64	66.29	74	8.6	161.86	154.08	172
3.8	71.52	68.08	76	8.7	163.74	155.88	174
3.9	73.40	69.87	78	8.8	165.63	157.67	176
4.0	75.28	71.66	80	8.9	167.51	159.46	178
4.1	77.16	73.45	82	9.0	169.39	161.25	180
4.2	79.05	75.25	84	9.1	171.27	163.04	182
4.3	80.93	77.04	86	9.2	173.16	164.84	184
4.4	82.81	78.83	88	9.3	175.04	166.63	186
4.5	84.69	80.62	90	9.4	176.92	168.42	188
4.6	86.58	82.42	92	9.5	178.80	170.21	190
4.7	88.46	84.21	94	9.6	180.68	172.00	192
4.8	90.34	86.00	96	9.7	182.57	173.80	194
4.9	92.22	87.79	98	9.8	184.45	175.59	196

Legal Titre.	New Denier.	Old Denier.	Internat. Denier.	Legal Titre.	New Denier.	Old Denier.	Internat. Denier.
Weight of 500 Metres in Grams.	Weight of 500 Metres in Deniers.	Weight of 476 Metres in Deniers.	Weight of 10,000 Metres in Grams.	Weight of 500 Metres in Grams.	Weight of 500 Metres in Deniers.	Weight of 476 Metres in Deniers.	Weight of 10,000 Metres in Grams.
9.9	186.33	177.38	198	11.0	207.03	179.10	220
10.0	188.21	179.17	200	11.1	208.92	198.09	222
10.1	190.09	180.97	202	11.2	210.80	200.68	224
10.2	191.98	182.76	204	11.3	212.68	202.47	226
10.3	193.86	184.55	206	11.4	214.56	204.26	228
10.4	195.74	186.35	208	11.5	216.45	206.06	230
10.5	197.62	188.14	210	11.6	218.33	207.85	232
10.6	199.51	189.93	212	11.7	220.21	209.64	234
10.7	201.39	191.72	214	11.8	222.09	211.43	236
10.8	203.27	193.51	216	11.9	223.97	213.22	238
10.9	205.15	195.30	218	12.0	225.86	215.01	240

The following table shows the comparison between drams, grams, and deniers:

Drams.	Grams.	Deniers.	Drams.	Grams.	Deniers.
0.0299	0.05313	1.0	2.50	4.43	83.4
0.25	0.44	8.3	2.75	4.87	91.6
0.50	0.88	16.5	3.00	5.31	100.0
0.568	1.00	18.82	4.00	7.09	133.0
0.75	1.33	25.0	5.00	8.86	166.0
1.00	1.771875	33.36	6.00	10.63	199.0
1.25	2.21	41.6	7.00	12.40	233.0
1.50	2.65	50.	8.00	14.17	265.0
1.75	3.10	58.3	9.00	15.95	299.0
2.00	3.54	66.6	10.00	17.72	333.0
2.25	3.98	75.0			

For the sizing of spun silk the unit of the English scale is a hank of 840 yards, and the number of such hanks in one pound is the count of the yarn. There is a difference in the counting of doubled spun silk from that of doubled cotton yarn, in that with cotton "2-40's" means single 40's doubled to 20's; whereas, with spun silk, "2-40's" means single 80's doubled to 40's, and "3-40's" would mean single 120's tripled to 40's, etc.

CHAPTER VII.

CHEMICAL NATURE AND PROPERTIES OF SILK.

1. Chemical Constitution.—The glands of the silkworm appear to secrete two transparent liquids. The one, **fibroin,** constituting from one-half to two-thirds of the entire secretion, forms the interior and larger portion of the silk fibre; the other, **sericin,** also called *silk-glue,* forms the outer coating of the fibre. The latter substance is yellowish in color, and is readily soluble in boiling water, hot soap, and alkaline solutions. As soon as discharged into the air, the fluids from the spinneret solidify, and coming into contact with each other at the moment of discharge are firmly cemented together by the sericin.

The amount of sericin present in raw silk is about 25 per cent., and this causes the fibre to feel harsh and to be stiff and coarse. Before being manufactured into textiles, the raw silk is subjected to several processes with a view to making it soft and glossy. The first treatment is called *discharging, stripping,* or *degumming,* and has for its purpose the removal of the silk-glue. It is really a scouring operation, the silk being worked in a soap solution * at a temperature of 95° C. In this process the silk loses from 20 to 30 per cent. in weight, but becomes soft and glossy. After several successive scourings the soap solution becomes heavily charged with sericin, and is subsequently utilized in the dye-bath as an assistant under the name of **boiled-off liquor.**

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* Alkaline carbonates are not to be recommended for silk scouring, as they are liable to injure the fibre, especially at elevated temperatures. Soft water should also be employed, as lime makes the fibre brittle.

According to Mulder, samples of yellow Italian silk analyzed as follows:

	Per Cent.
Silk fibre	53.35
Matter soluble in water	28.86
" " " alcohol	1.48
" " " ether	0.01
" " " acetic acid	16.30

He gives the chemical composition of the silk fibre as follows:

	Per Cent.
Fibroin	53.37
Gelatin	20.66
Albumin	24.43
Wax	1.39
Coloring-matter	0.05
Resinous and fatty matter	0.10

According to Richardson, mulberry silk has the following composition:

	Per Cent.
Water	12.50
Fats	0.14
Resins	0.56
Sericin	22.58
Fibroin	63.10
Mineral matter	1.12

Analyses of samples of mulberry silk are given by H. Silbermann as follows:

	White.		Yellow.	
	Cocoons.	Raw.	Cocoons.	Raw.
Fibroin	73.59	76.20	70.02	72.35
Ash of fibroin	0.09	0.09	0.16	0.16
Sericin	22.28	22.01	24.29	23.13
Wax and fat	3.02	1.36	3.46	2.75
Salts	1.60	0.30	1.92	1.60

The amount of ash in boiled-off silk will vary somewhat according to the origin of the silk, but will average about 0.50 per cent. In raw silk the average amount of ash will be about

1 per cent.*   In yama-mai silk the ash may reach as high as 8 per cent.

Fibroin is a proteid somewhat analogous to that contained in wool, and, like the latter, it is no doubt an amido-acid.†   Mulder gives the analysis of fibroin as follows:

	Per Cent.
Carbon	48.80
Hydrogen	6.23
Oxygen	25.00
Nitrogen	19.00

Vignon analyzed samples of highly purified silk,‡ and gives the following figures:

	Per Cent.
Carbon	48.3
Hydrogen	6.5
Nitrogen	19.2
Oxygen	26.0

The proportion of fibroin in raw silk has been variously stated by different observers, and appears to differ with the method employed for its determination.§   The figure given by

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* Allen states that the greater part of the mineral matters of raw silk are simply adherent to the fibre, and are removed together with the sericin by prolonged boiling with soap solution; the residual fibroin retains only about 0.6 per cent. of mineral matter. (*Comm. Org. Anal.*, vol. 4, p. 507.)

† Richardson suggests the following structural formula for fibroin, allowing x to represent a hydrocarbon residue:

$$x \left\langle \begin{matrix} NH—CO \\ CO—NH \end{matrix} \right\rangle x.$$
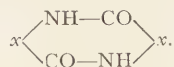
The decomposition of fibroin by saponification with potash would then be

$$x \left\langle \begin{matrix} NH—CO \\ CO—NH \end{matrix} \right\rangle x + 2KOH = 2x \left\langle \begin{matrix} NH_2 \\ CO.OK \end{matrix} \right.$$
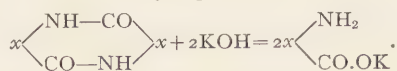
‡ Vignon prepared pure fibroin in the following manner: A 10-gram skein of raw white silk is boiled for thirty minutes in a solution of 15 grams of neutral soap in 1500 c.c. water; rinse in hot, then in tepid water; squeeze and repeat the treatment in a fresh soap-bath; rinse with water, then with dilute hydrochloric acid, again with water; finally, wash twice with 90 per cent. alcohol. The fibroin thus obtained leaves only 0.01 per cent. of ash on ignition. (*Compt. rend.*, vol. 115, pp. 17, 613.)

§ According to Allen, raw commercial silk from the mulberry silkworm is generally regarded as containing 11 per cent. of moisture, 66 per cent. of fibroin, 22 per cent. of sericin, and 1 per cent. of mineral and coloring-matters. (*Comm. Org. Anal.*, vol. 4, p. 506.)

Mulder (see above) of 53.35 per cent. was obtained by boiling the raw silk with acetic acid. By the action of a 5 per cent. solution of cold caustic soda, Städeler obtained 42 to 50 per cent. of fibroin. Cramer obtained 66 per cent. by heating raw silk in water at 133° C. under pressure. Francézon reports 75 per cent. of fibroin by twice boiling the silk in a solution of soap and then treating with acetic acid. Vignon, by carefully purifying the fibroin by suitable treatment, obtained 75 per cent.*

Unlike keratin, the proteid of wool, fibroin contains no sulphur, and is much more constant in its composition. The empirical formula for fibroin as given by Mulder is $C_{15}H_{23}N_5O_6$. Mills and Takamine give the formula as $C_{24}H_{38}N_8O_8$, while Schützenberger gives $C_{71}H_{107}N_{24}O_{25}$. Cramer arrives at the same formula as Mulder, while Richardson (*Jour. Soc. Chem. Ind.*, vol. 12, 426) gives $C_{60}H_{94}N_{18}O_{25}$. Vignon's formula for specially purified fibroin is $C_{22}H_{47}N_{10}O_{12}$.†

The presence of the amido-group in fibroin has been shown, as in the case of wool (see page 41), by diazotizing the fibre with an acid solution of sodium nitrite, then washing and treating with solutions of various developers, such as phenol, resorcinol, alpha- and beta-naphthols, etc., whereby the fibre becomes dyed in different colors.

From its action towards alcoholic potash Richardson concludes that silk fibroin is probably an amido-anhydride rather than an amido-acid. When boiled for a long period with

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* According to Fischer and Skita (*Zeitschr. f. phys. Chem.*, vol. 33, p. 171, and vol. 35, p. 224), even technically purified silk still contains about 5 per cent. of silk-glue.

† Silbermann found that fibroin heated with a solution of barium hydrate under pressure was decomposed with the formation of oxalic, carbonic, and acetic acids, together with an amido-body approximating the formula $C_{68}H_{141}N_{21}O_{43}$. The latter compound is said to undergo further decomposition with the formation of tyrosin, glycocin, alanin, amido-butyric acid, and an amido-acid of the acrylic series. Fischer and Skita (*Zeitschr. f. physiol. Chem.*, vol. 33, p. 177) have shown that in all probability amino-valerianic acid, $C_3H_7.CH(NH_2).COOH$, occurs in fibroin. Silk fibroin, however, appears to differ from other albumins in not containing aspartic acid, $COOH.CH_2.CH(NH_2).CO.OH$. Glutaminic acid, $COOH.CH_2.CH_2.CH(NH_2).COOH$, also appears to be present in fibroin, though Fischer doubts this.

dilute sulphuric acid, fibroin is dissolved to a yellowish-brown liquid, leaving as a residue only a small amount of what is apparently a fatty acid. From this decomposition product Weyl (*Ber.*, vol. 21, 1529) succeeded in isolating 5.2 per cent. of tyrosin, 7.5 per cent. of glycocin, and 15 per cent. of a crystalline compound which was apparently alpha-alanin. Towards Millon's and Adamkiewitz's reagents fibroin gives the usual reaction of proteids, and it also gives the biuret test.* According to Richardson, silk fibroin will absorb 30 per cent. of iodin when treated with Hübl's reagent. Attempts have been made to acetylize fibroin, but without success.†

Fibroin is insoluble in ammonia and solutions of the alkaline carbonates; neither is it dissolved by a 1 per cent. solution of caustic soda, but stronger solutions affect it, especially if hot. From its solution in caustic soda fibroin may be reprecipitated by dilution with water. Fibroin is also soluble in hot glacial

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* Millon's reagent consists of a solution of mercurous nitrate containing nitrous acid in solution. It is prepared by treating 1 c.c. of mercury with 10 c.c. of nitric acid (sp. gr. 1.4), heating gently until complete solution is effected, then diluting the solution with twice its volume of cold water. When a solution of a proteid is treated with this reagent, a white precipitate is first formed, which turns brick-red on boiling; a solid proteid becomes red when boiled with the reagent. Adamkiewcz's test is to dissolve the proteid in glacial acetic acid, and then add concentrated sulphuric acid to the solution, when a fine violet color will be produced, and the liquid will exhibit a faint fluorescence. The biuret test is to add a few drops of a dilute solution of copper sulphate to the solution of proteid; on then adding an excess of caustic soda solution the precipitate which at first formed will be dissolved with the production of a fine violet coloration.

† Cohnheim, in his tables of the percentage composition of various albumins, gives the following for the fibroin of silk:

	Per Cent.
Glycocoll	36
Alanin	21
Leucin	1.5
Phenylalanin	1.5
α-Pyrrolidin-carboxylic acid	0.3
Serin	1.6
Tyrosin	10
Arginin	1

The occurrence of the following compounds in indeterminate amounts is also given: Lysin, histidin, tryptophane, and amino-valerianic acid.

acetic acid, and in strong hydrochloric, sulphuric, nitric, and phosphoric acids. Alkaline solutions of the hydroxides of such metals as nickel, zinc, and copper also dissolve fibroin.

If silk fibroin is dissolved in cold concentrated hydrochloric acid, and the solution be allowed to stand sixteen hours at the ordinary temperature with three times its volume of hydrochloric acid (sp. gr. 1.19), it will no longer be precipitated by the addition of alcohol. The fibroin appears to have suffered hydrolysis, being converted into a body similar to peptone. This substance may be separated out by steaming the above solution under diminished pressure.* If its aqueous solution be neutralized with ammonia and some trypsin ferment be added, tyrosin will begin to crystallize out in a few hours.

Sericin, according to the analysis of Richardson, has the following composition:

	Per Cent.
Carbon	48.80
Hydrogen	6.23
Oxygen	25.97
Nitrogen	19.00

and its formula is given as $C_{16}H_{25}N_5O_8$. It is considered by some as an alteration product of fibroin; strong hydrochloric acid is said to convert the latter into sericin; the conversion is supposed to take place by assimilation of water and oxygen.

$$C_{15}H_{23}N_5O_6 + H_2O + O = C_{16}H_{25}N_5O_8.$$
Fibroin   Sericin
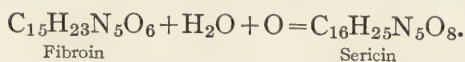
Sericin may be obtained in a pure condition by first boiling a sample of raw silk in water for several hours, after which the

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* Fischer and Abderhalden (*Berichte*, 1906, p. 752) have succeeded in isolating from the hydrochloric acid solution of silk fibroin a dipeptide in the form of methyl-diketopiperazine, having the formula

$$NH \Big\langle {\,CH_2.CO \atop CO.CH} \Big\rangle {NH. \atop CH_3}$$
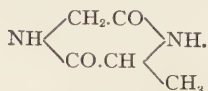
The yield is about 12 per cent., and the product is identical with that obtained synthetically from glycocoll and *d*-alanin.

sericin is precipitated by lead acetate.* On treatment with dilute sulphuric acid, sericin yields a small quantity of leucin and tyrosin, but no trace of glycocoll, the principal product formed being a crystalline body called *serin*, which appears to have the formula $C_2H_4 \begin{cases} NH_2 \\ COOH \end{cases}$, and from its chemical reactions is evidently analogous to glycocin, probably being amido-glyceric acid.

Sericin is soluble in hot water, hot soap solutions, and dilute caustic alkalies. The aqueous solution is precipitated by alcohol, tannin, basic lead acetate, stannous chloride, bromin, and iodin, and by potassium ferrocyanide in the presence of acetic acid.† Mulder gives the formula of $C_{15}H_{25}N_5O_8$ to sericin, and the following composition:

	Per Cent.
Carbon	42.60
Hydrogen	5.90
Oxygen	35.00
Nitrogen	16.50

According to Bolley, the composition of sericin is

	Per Cent.
Carbon	44.32
Hydrogen	6.18
Oxygen	31.20
Nitrogen	18.30

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* Pure sericin may also be prepared by precipitating crude sericin solution with 1 per cent. acetic acid, washing the separated sericin by repeated decantation with water, then treating with cold and afterwards with boiling alcohol, and finally extracting with ether. Pure sericin contains

Carbon	45.00 per cent.
Hydrogen	6.32 " "
Nitrogen	17.14 " "
Oxygen	31.54 " "

It is easily soluble in water, in concentrated hydrochloric acid, and in potassium carbonate; sodium carbonate only causes a swelling.

† By treatment with formaldehyde, it is claimed that sericin is rendered insoluble in both hot water and soap solutions; consequently, raw silk may be treated with this reagent for use in certain applications where it may be desired to retain as far as possible the coating of silk-glue.

According to the tables of Cohnheim, the percentages of known constituents in silk-glue are as follows:

	Per Cent.
Glycocoll	0.1—0.2
Alanin	5
Leucin	Not determined
Serin	6.6
Tyrosin	5
Lysin	Not determined
Arginin	4
Ammonia	1.87

Vignon,* by observing the action of solutions of sericin and fibroin on polarized light, found that both of these constituents of silk were lævogyrate, and their rotatory powers were about equal, approximating to 40°. This is in keeping with observations made on other albuminoids.

According to Dubois,† the yellow coloring-matter of silk is similar to carotin. He obtained five different bodies from the natural coloring-matter of silk, as follows: (1) a golden-yellow coloring-matter, soluble in potassium carbonate and precipitated by acetic acid; (2) crystals which appear yellowish-red by transmitted light and brown by reflected light; (3) a lemon-colored amorphous body, the alcoholic solution of which on evaporation gave granular masses; (4) yellow octahedral crystals resembling sulphur; (5) a dark bluish-green pigment in minute quantities and probably crystalline.

2. Chemical Reactions.—In its general chemical behavior silk is quite similar to wool. It will stand a higher **temperature**, however, than the latter fibre, without receiving injury; it can be heated, for instance, to 110° C. without danger of decomposition; at 170° C., however, it is rapidly disintegrated. On **burning** it liberates an empyreumatic odor which is not as disagreeable as that obtained from burning wool. Silk readily absorbs **dilute acids** from solutions, and in so doing increases in lustre and acquires the scroop of which mention has already been made. Unlike wool, it has a strong affinity for **tannic acid**, which fact is utilized for both weighting and mordanting the fibre. Silk

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* *Compt. rend.*, vol. 103, p. 802.   † *Ibid.*, vol. 111, p. 482.

also absorbs **sugar** to a considerable degree, and this substance may be employed as a weighting material for light-colored silks on this account. Towards the ordinary **metallic salts** used as mordants silk exhibits quite an affinity; in fact, to such an extent can it absorb and fix certain metallic salts that silk material is frequently heavily mordanted with such salts for the purpose of unscrupulously increasing its weight.

Solutions of sodium chloride appear to have a peculiar action on the silk fibre, especially in the presence of weighting materials. According to the researches of Sisley, solutions of common salt acting on weighted silk in the presence of air and moisture cause a complete destruction of the fibre in twelve months, if charged with but 0.5 per cent. of salt; 1 per cent. of salt causes a very pronounced tendering of the fibre in two months, while 2 to 5 per cent. of salt causes a distinct tendering in seven days. The action of the salt is shared in a lesser degree by the chlorides of potassium, ammonium, magnesium, calcium, barium, aluminium, and zinc, and is probably due to chemical dissociation. This fact may account for the stains sometimes found in skeins of silk which also show a tendering of the fibre. These stains have frequently been noticed, and thorough investigation has failed to satisfactorily account for them. The salt may get into the fibre through the perspiration of the workmen handling the goods, or through a variety of other causes.

Silk is not as sensitive to **dilute alkalies** as wool, though the lustre of the fibre is somewhat diminished.* When treated with strong hot caustic alkalies the silk fibre dissolves. Ammonia and soaps have no effect on silk beyond dissolving the silk-glue or sericin; though on long-continued boiling in soap, the fibroin is also attacked. Borax has no injurious action on silk, but neither has it any special solvent action on silk-glue, hence it is not serviceable as a stripping agent. If raw silk is steeped in lime-water, the fibre will swell to some extent and the silk-glue will become somewhat softened. If the action of the lime-water is continued, however, the silk will become brittle. Concentrated

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* It is said that when mixed with glucose or glycerin caustic soda does not dissolve the silk fibre to any extent, but only removes the gum.

sulphuric * and hydrochloric acids † dissolve silk; nitric acid ‡ colors silk yellow,§ as in the case with wool, probably due to the formation of xanthoproteic acid. This color can be removed by treatment with a boiling solution of stannous chloride. The solubility of silk in strong hydrochloric acid is very rapid, a minute or two sufficing for complete solution. Under such conditions wool and cotton fibres are but slightly affected, so such a treatment may be used for the separation of silk from wool or cotton for the purpose of analysis. A concentrated solution of basic zinc chloride readily dissolves the silk fibre.‖ An

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* Though silk is soluble in concentrated acids if their action is continued for any length of time, it appears that if silk be treated with concentrated sulphuric acid for only a few minutes, then rinsed and neutralized, the fibre will contract from 30 to 50 per cent. in length without otherwise suffering serious injury beyond a considerable loss in lustre. This action of concentrated acids on silk has been utilized for the craping of silk fabrics, the acid being allowed to act only on certain parts of the material. It appears that tussah silk is not affected by the acid to the same degree as ordinary silk, and hence craping may be accomplished by mixing tussah with ordinary silk, and treating the entire fabric with concentrated acid.

† According to Farrell (*Jour. Soc. Dyers' & Col.*, 1905, p. 70), when silk is treated with hydrochloric acid of a density of 29° Tw. it shrinks about one-third without any appreciable deterioration in the strength of the fibre. With solutions of acid below 29° Tw. no contraction occurs, while with solutions above 30° Tw. complete disintegration of the fibre results. In the production of crepon effects by this method, the fabric is printed with a wax resist, and is then immersed in the hydrochloric acid; the contraction is complete in one to two minutes, after which the fabric is well washed in water. Nitric acid and ortho-phosphoric acid may also be employed for the craping of silk fabrics (see C. and P. Depoully, *Jour. Soc. Dyers' & Col.*, 1896, p. 8). According to a French patent, a similar effect may be obtained by treating silk with a solution of zinc chloride of from 32° to 76° Tw. (see *Jour. Soc. Dyers' & Col.*, 1899, p. 214).

‡ Vignon and Sisley (*Compt. rend.*, 1891) found that the purified fibroin of silk when treated with nitrous nitric acid increased 2 per cent. in weight.

§ The action of nitric acid on silk is rather a peculiar one. When treated for one minute with nitric acid of sp. gr. 1.33 at a temperature of 45° C., the silk acquires a yellow color which cannot be washed out and is also fast to light. Pure nitric acid free from nitrous compounds, however, does not give this color. On treating the yellow nitro-silk with an alkali, the color is considerably deepened. With strong sulphuric acid nitro-silk swells up and gives a gelatinous mass resembling egg albumin.

‖ On diluting this solution with water a flocculent precipitate is obtained which is soluble in ammonia, and the latter solution has been employed for coating vegetable fibres with silk for the production of certain so-called "artificial silks."

acid solution of zinc chloride acts in the same manner. Solutions of copper oxide or nickel oxide in ammonia also act as solvents towards silk. The latter solution can be employed for separating silk from cotton, the silk being readily and completely soluble in a boiling solution of ammoniacal nickel oxide, whereas cotton loses less than 1 per cent. of its weight. A boiling solution of basic zinc chloride (1 : 1) will dissolve silk in one minute, while cotton under the same treatment loses only 0.5 per cent., and wool only 1.5 to 2 per cent.* Chlorin destroys silk, as do other oxidizing agents, unless employed in very dilute solutions and with great care. Strong solutions of stannic chloride (70° Tw.) will dissolve silk, an action which should be borne in mind when mordanting and weighting silk with this salt.

Hydrofluosilicic acid and hydrofluoric acid in the cold and in 5 per cent. solutions do not appear to exert any injurious action on the silk fibre; these acids, however, remove all inorganic weighting materials, and their use has been suggested for the restoring of excessively weighted silks to their normal condition, so that they may be less harsh and brittle.

Towards **coloring-matters** in general, silk exhibits a greater capacity of absorption than perhaps any other fibre. It also absorbs dyestuffs at much lower temperatures than does wool.

As silk is evidently an amido-acid, it possesses distinct chemical characteristics; that is to say, it exhibits both acid and basic properties in a manner similar to wool. Like the latter fibre (see page 50), it is probable that the active chemical groups in silk have considerable influence on its dyeing properties, especially with reference to acid and basic dyes, for it has been shown † that if these active molecular groups are rendered inactive by acetylation or otherwise, the dyeing properties of the silk are accordingly altered.

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* Silk is also soluble in Schweitzer's reagent (ammoniacal copper oxide), and in an alkaline solution of copper sulphate and glycerin. The latter is used to separate silk from wool and cotton; and the following solution is recommended: 16 grams copper sulphate, 10 grams glycerin, and 150 c.c. of water. After dissolving, add a solution of caustic soda, until the precipitate which at first forms is just redissolved.

† Suida, *Färber-Zeit.*, 1905.

3. Tussah Silk presents a number of differences, both physical and chemical, from ordinary silk. It has a brown color and is considerably stiffer and coarser. It is less reactive, in general, towards chemical reagents, and consequently presents more difficulty in bleaching and dyeing. Tussah silk requires a much more severe treatment for degumming than cultivated silk, and the boiled-off liquor so obtained is of no value in dyeing.

According to analyses of Bastow and Appleyard,* raw tussah silk gives the following results:

	Per Cent.
Soluble in hot water	21.33
Dissolved by alcohol (fatty acid)	0.91
Dissolved by ether	0.08
Total loss on boiling off with 1 per cent. solution of soap	26.49
Mineral matter	5.34

These same observers consider that the fibroin of tussah silk differs chemically from that of ordinary silk, as it is not so readily acted on by solvents. In order to obtain pure tussah fibroin, the silk should be boiled repeatedly with a 1 per cent. solution of soap, washed with water, extracted with hydrochloric acid; and after again washing with water and drying, extracted successively with alcohol and ether. Tussah fibroin purified in this manner shows the following composition:

	Per Cent.
Carbon	47.18
Hydrogen	6.30
Nitrogen	16.85
Oxygen	29.67

These figures are exclusive of 0.226 per cent. of ash. Appleyard gives the following analysis of the ash from raw tussah silk.

	Per Cent.
Soda, Na_2O	12.45
Potash, K_2O	31.68
Alumina, Al_2O_3	1.46
Lime, CaO	13.32
Magnesia, MgO	2.56
Phosphoric acid, P_2O_5	6.90
Carbonic acid, CO_2	11.14
Silica, SiO_2	9.79
Hydrochloric acid, Cl	2.89
Sulphuric acid, SO_3	8.16

* *Jour. Soc. Dyers' & Col.*, vol. 4, p. 88.

The presence of sulphates in this ash is somewhat remarkable, as this constituent does not occur in ordinary silk. The occurrence of alumina is also remarkable, as this element is seldom a constituent of animal tissues. As the amount of ash of purified fibroin of both common silk and tussah silk is very much lower than that of the raw silks, it is to be considered probable that most of the mineral matter found is derived from adhering impurities, and is not a true constituent of the silk itself.

Tussah silk is scarcely affected by an alkaline solution of copper hydrate in glycerin, whereas ordinary silk is readily soluble in this reagent.*

The following table exhibits the principal differences between true silk and tussah silk: †

Reagent.	Mulberry Silk.	Tussah Silk.
Hot caustic soda (10%)	Dissolves in 12 minutes	Requires 50 minutes for solution
Cold hydrochloric acid (sp. gr. 1.16)	Dissolves very rapidly	Only partially dissolves in 48 hours
Cold conc. nitric acid	Dissolves in 5 minutes	Dissolves in 10 minutes
Neutral solution of zinc chloride (sp. gr. 1.725)	Dissolves very rapidly	Dissolves but slowly
Strong chromic acid solution in water	Dissolves very rapidly	Dissolves very slowly

While the fibre of mulberry silk presents the appearance of a structureless thread, and rarely exhibits signs of distinct striation, tussah (and other " wild " silks) is made up of bundles of delicate fibrillæ, varying in diameter from 0.0003 to 0.0015 mm., so that the fibre as a whole presents a striated appearance. Also the cross-section ‡ of tussah silk is considerably larger than that of mulberry silk, and is more flattened; it also exhibits numerous fine air-tubes. The following table exhibits the difference in the microscopic appearance of various kinds of raw silk; the diameter is expressed in μ=thousandths of a millimetre: §

* Filsinger, *Chem. Zeit.*, vol. 20, p. 324.
† Bastow and Appleyard, *Jour. Soc. Dyers' & Col.*, vol. 4, p. 89.
‡ Filsinger, *vide supra.*
§ Höhnel, *Jour. Soc. Chem. Ind.*, vol. 2, p. 172.

Variety of Silk.	Diameter, μ.	Appearance.	
		Broad Side.	Narrow Side.
True silk, *Bombyx mori*	20 to 25	White or yellowish; shiny	White or yellowish; shiny
Senegal silk, *B. faidherbi*	30 to 35	Shining yellowish or brownish white, or pale yellow, gray, brown, and occasionally bluish white	Gray, brown, or black, with occasionally lighter shades
Ailanthus silk, *Attacus cynthia*	40 to 50	Shining yellowish white, with yellow, brown, or brownish-gray spots	Dirty gray or brown to black, with green, yellow, red, violet, or blue spots
Yama-mai silk, *Antheræa yama-mai*	40 to 50	Bluish white with dark blue, blue and black shades	Glaring and fine colors, with dark or black shades
Tussah silk, *Attacus selene*	50 to 55	Irregular in thickness. Thickest parts with gray and blue spots; thinner parts bluish white, yellow, or orange-red	Dark gray, with pink or light green spots
Tussah silk, *Antheræa mylitta*	60 to 65	Similar to above, but spots orange-red, red, or brown	Similar to above

The cocoon-threads of wild silks possess greater elasticity and tensile strength, as would naturally be expected from their greater thickness. The following table gives the elasticity and breaking strain of the principal varieties of silk:

Variety of Silk.	Elasticity, Per Cent.	Breaking Strain, Grams.
Mulberry (*Bombyx mori*)	13.3	4.5
Tussah (*Antheræa mylitta*)	19.1	12.8
Eria (*Attacus ricini*)	15.0	4.0
Muga (*Antheræa assama*)	21.7	6.7
Atlas (*Attacus altas*)	19.1	5.6
Ailanthus (*Attacus cynthia*)	22.5	4.9
Yama-mai	25.0	12.8
Attacus Selene	20.0	5.6
Antheræa pernyi	19.1	8.1

CHAPTER VIII.

THE VEGETABLE FIBRES.

1. General Considerations.—The basis of all vegetable fibres is to be found in cellulose,* a compound belonging to a class of naturally occurring substances known as carbohydrates. The fibres may be *seed-hairs*, such as the different varieties of cotton, cotton-silk, etc.;† or *bast fibres*, which include those obtained from the cambium layer of the dicotyledonous plants, such as flax, hemp, jute, ramie, etc.; or *vascular fibres*,‡ which include those obtained chiefly from the leaf-tissues of the monocotyledonous plants, such as phormium, agave, aloe, etc.§

Anatomically considered, the plant fibres may be divided into six different classes (Höhnel):

(1) Single-cell plant-hairs, such as cotton, vegetable silk, and vegetable down.

(2) Fibres consisting of several cells, such as pulu fibre, elephant-grass, and cotton-grass.

(3) Bast fibres, such as flax, hemp, jute, ramie, etc.

(4) Dicotyledonous bast fibres, such as linden bast, Cuba bast, etc.

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* It is seldom, however, that cellulose actually occurs in the plant in the free condition, but is usually associated or chemically combined with other substances, of which the principal are fatty and waxy matters, coloring-matters, and tannins, and a rather indefinite group of so-called pectin matters, which appear to be more or less oxidized or acid derivatives of the carbohydrates.

† In a certain sense, the cocoanut fibre (coir) may be included under the class of seed-hairs.

‡ In China there is an example of a spinning fibre composed of the *leaf-hairs* of a plant. The latter apparently belongs to the *Xeranthemum*, and its leaves are covered with a thick mass of long hairy fibres, which are easily separated from the leaf when dried (see Wiesner, *Die Rohstoffe des Pflanzenreiches*, p. 167).

§ There is a peculiar instance in which the entire plant is used as the fibre; this is sea-grass or sea-wrack (*Zostera marina*). However, it can scarcely be considered as a textile fibre, as it is almost altogether employed for stuffing and packing.

(5) Monocotyledonous vascular fibres, such as sisal hemp, aloe hemp, pineapple fibre, cocoanut fibre, etc.

(6) Monocotyledonous sclerenchymous fibres, such as Manila hemp, New Zealand flax, etc.*

There is considerable difference to be observed between the anatomical structure of seed-hairs and that of bast fibres. **Seed-hairs** are known botanically as plumose fibres, and usually consist of a unicellular fibre or trichrome, exhibiting only a single solid apex, the other end being attached to the seed. Externally they appear to be covered with a thin skin or cuticle which differs essentially from the remaining cellulose in that it is not dissolved by treatment with sulphuric acid. The cell-walls vary considerably in their thickness, and are structureless and porous. Through the centre of the fibre runs a hollow canal called the *lumen.* Usually the dried fibre is flattened into the form of a band, so that in cross-section the lumen appears as a line. **Bast fibres,** on the other hand, consist of completely enclosed tubes, each end being pointed. Each individual fibre is multicellular, the cells being long and usually polygonal in cross-section.† The cell-walls are usually rather thick, and the cross-section instead of being flat and narrow is broad and more or less rounded. The inner wall is frequently covered with a thin layer of dried protoplasm. One of the most characteristic appearances of the bast fibres is the occurrence of *dislocations* or joints through-

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* Zipser (*Textile Raw Materials*, p. 8 *et seq.*) gives the following classification for vegetable fibres:

1. *Seed* fibres, growing from the seeds or seed-capsules of certain plants, and including cotton, *Bombax, Asclepias,* etc.

2. *Stem* fibres, growing in the bast of certain dicotyledonous plants, and including flax, hemp, jute, etc.

3. *Leaf* fibres, occurring in the leaves of a number of monocotyledonous plants, and including New Zealand hemp, Manila hemp, aloe, etc.

4. *Fruit* fibres, of which the sole member worth mentioning is the cocoanut fibre.

† The bast or vascular bundles consist of two parts, the *phloëm* and the *xylem.* As a rule, the phloëm occurs nearer the outside of the plant, while the xylem forms the principal structural part of the inside portion of the plant. The fibres in the phloëm are usually rather easily detached and form the commercial product, while those occurring in the xylem, as a rule, cannot be readily separated by mechanical means from the woody tissue in which they are imbedded.

out the length of the fibre (see Fig. 42). These dislocations also show the property of becoming more deeply colored than the rest of the fibre when treated with a solution of chlor-iodide of zinc. These knots or joints generally show thicker overlying transverse fissures, between which lie small short discs arranged on edge. The joints disappear altogether in the monocotyledonous fibres; they are also lacking on many true bast fibres, such as jute, linden bast, etc., but occur in hemp, flax, ramie, etc.
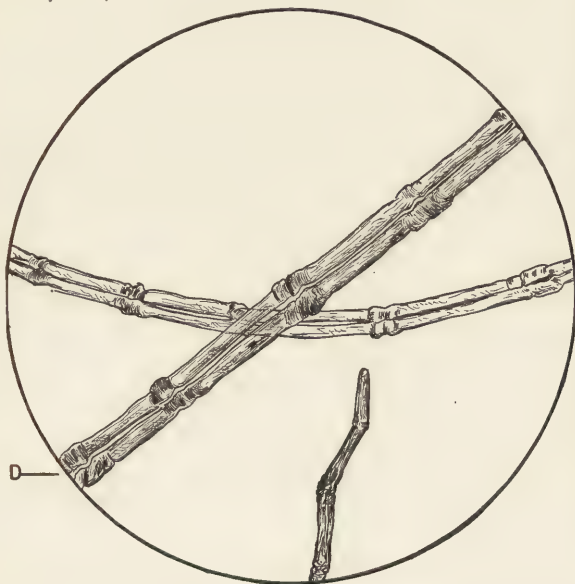
FIG. 42.

FIG. 43.

FIG. 42.—A Typical Bast Fibre (×350) showing the Jointed Structure or Dis-
locations at *D*. (Micrograph by author.)

FIG. 43.—A Bundle of Bast Fibres. (×400.) (After Lecomte.)

Bast fibres are the long, tough cells found in the barks and stems of various plants. The cell-walls of these fibres are usually partially changed from pure cellulose into lignin and are thickened. There is usually a considerable amount of foreign matter also contained in the cell-wall, and often this becomes sufficiently characteristic to serve as a means of identifying the various fibres by the application of chemical reagents. Fibres which contain only pure cellulose are colored blue when treated with

the iodin-sulphuric acid reagent (see chapter xvii), while fibres containing lignin are colored yellow to brown with the same test. Unlike seed-hairs, the individual cells of bast fibres are not of sufficient length for use in spinning, but as they are held together with considerable firmness to form bundles of great length, they are utilized in this form.

Wiesner gives the following table showing the length of the raw fibre and the dimensions of the cells composing them.

Fibre.	Length of Raw Fibre, cm.	Length of Cells, mm.	Breadth of Cells.		
			Min. μ.	Max. μ.	Aver. μ.
Tillandsia fibre....................	2–22	0.2–0.5	6	15	
Esparto grass......................	10–40	1.5–1.9	9	15	
Cordia latifolia....................	50–90	0.1–1.6	14.7	16.8	15
Phormium tenax...................	80–110	2.5–5.6	8	29	13
Abelmochus tetraphyllos............	60–70	0.1–1.6	8	20	16
Bauhinia racemosa.................	50–150	1.5–4.0	8	20	
Jute (Corchorus capsularis).........	150–300	0.8–4.1	10	21	16
Thespesia lampas..................	100–180	0.9–4.7	12	21	16
Urena sinuata.....................	100–120	1.1–3.2	9	24	15
Sida retusa.......................	80–100	0.8–2.3	15	25	
Calotropis gigantea (bast)..........	20–30	0.7–3.0	18	25	
Aloe perfoliata....................	40–50	1.3–3.7	15	24	
Flax (Linum usitatissimum).........	20–140	2.0–4.0	12	25	16
Hemp (Cannabis sativo)............	100–300	0.8–4.1	16	32	20
Jute (Corchorus olitorius)..........	150–300	0.8–4.1	16	32	20
Hibiscus cannabinus..............	40–90	4.0–12.0	20	41	
Sunn (Crotolaria juncea)..........	20–50	0.5–6.9	20	42	
Bromelia karatas..................	100–110	1.4–6.7	27	42	
China grass (Böhmeria nivea)......	....	22.0	40	80	50
Ramie (Böhmeria tenacissima)......	....	8.0	16	12.6	
Cotton (Gossypium barbadense).....	4.05	40.5	19.2	27.9	25.2
do. (G. conglomeratum)..........	3.51	35.1	17	27.1	25.9
do. (G. herbaceum).............	1.82	18.2	11.9	22	18.5
do. (G. acuminatum)...........	2.84	28.4	20.1	29.9	29.4
do. (G. arboreum)..............	2.50	25.0	20	37.8	29.9
Cotton wool (Bombax heptaphyllum).	2–3	20–30	19	29	
Vegetable silk (Calotropis gigantea)..	2–3	20–30	12	42	38
do. (Asclepias).............	....	10–30	20	44	
do. (Marsdenia)...........	....	10–25	19	33	
do. (Strophanthus).......	....	10–56	49	92	
do. (Beaumontia).........	....	30–45	33	50	
Linden-bast........	....	1.1–2.6	......	......	15
Sterculia villosa...................	....	1.5–3.5	17	25	20
Holoptelia integrifolia..............	....	0.9–2.1	9	14	12
Kydia calycina....................	....	1–2	17	24	
Lasiosyphon speciosus..............	....	0.4–5.1	8	29	
Sponia wightii....................	....	4	......	......	21
Pandanus odoratissimus............	....	1.0–4.2	......	......	20
Pita fibre........................	....	1.0–2.2	16	21	17
Coir fibre....	....	0.4–0.9	12	20	16

Vétillard gives a somewhat similar table as follows:

Name.	Length (in mm.)			Breadth (in μ)			Ratio of Breadth to Length.
	Min.	Max.	Mean.	Min.	Max.	Mean.	
Linen..........................	4	66	25	15	37	20	1200
Hemp (*Cannabis sativa*)...........	5	55	20	16	50	22	1000
Hop fibre (*Humulus lupulus*)......	4	19	10	12	26	16·	620
Nettle fibre (*Urtica dioica*)........	4	57	27	20	70	50	550
Ramie (*Urtica nivea*).............	60	250	120	....	80	50	2400
Fibre of paper mulberry...........	....	25	10	....	....	30	350
Sunn hemp (*Crotalaria juncea*). ...	4	12	8	25	50	30	260
Broom-grass (*Sarothamnus vulgario*)	2	9	5	10	25	15	330
Feather-grass (*Spartium junceum*)..	5	16	10	....	....	20	500
Meliotus alba.....................	5	18	10	20	36	30	330
Cotton..........................	10	40					
Gambo hemp (*Hibiscus cannabinus*)	2	6	5	14	33	21	240
Linden-bast (*Tilia europæa*).......	1.2	5	2	14	20	16	125
Jute (*Corchorus capsularis*)........	1.5	5	2	20	25	22.5	90
Lagetta lintearia.................	3	6	5	10	20	....	500
Salix alba......................	....	3	2	17	30	22	90
Esparto.........................	0.5	3.5	1.5	7	18	12	125
Lygæum spartum.................	1.3	4.5	2.5	12	20	15	160
Pineapple fibre...................	3	9	5	4	8	6	830
Bromelia karatas.................	2.5	10	5	20	32	24	210
Bromelia pinguin.................	0.8	2.5	2	8	16	13	150
New Zealand flax (*Phormium tenax*).	5	15	9	10	20	16	550
Yucca fibre......................	0.5	6	4	10	20	15	170
Sanseveria fibre..................	1.5	6	3	15	26	20	150
Pita (*Agave americana*)...........	1.5	4	2.5	20	32	24	100
Manila hemp (*Musa textilis*).......	3	12	6	16	32	24	250
Musa paradisaica.................	....	....	5	20	40	28	180
Phœnix dactylifera...............	2	6	3	16	24	20	150
Corypha umbraculifera...........	1.5	5	3	16	28	24	120
Elais guineensis.................	1.5	3.5	2.5	10	13	11	230
Raphia taetigera.................	1.5	3	2.5	12	20	16	160
Mauritia flexuosa................	1	3	1.5	10	16	12	130
Coir fibre (*Cocas nucifera*)........	0.4	1	0.7	12	24	20	35

2. Classification.—Perhaps the most systematic and complete enumeration of the various vegetable fibres, together with a classification of their technical uses, is that given by Dodge,* from which the following abstract is taken.

STRUCTURAL CLASSIFICATION.

A. FIBROVASCULAR STRUCTURE.

1. *Bast fibres.*—Derived from the inner fibrous bark of dicotyledonous plants or exogens, or outside growers. They are

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* *Report on Useful Plant Fibres of the World.*

composed of bast-cells, the ends of which overlap each other, so as to form in mass a filament. They occupy the phloëm portion of the fibrovascular bundles, and their utility in nature is to give strength and flexibility to the tissue.

2. *Woody fibres.*

(*a*) The stems and twigs of exogenous plants, simply stripped of their bark and used entire, or separated into withes for weaving or plaiting into basketry.

(*b*) The entire or subdivided roots of exogenous plants, to be employed for the same purpose, or as tie material, or as very coarse thread for stitching or binding.

(*c*) The wood of exogenous trees easily divisible into layers or splints for the same purposes, or more finely divided into thread-like shavings for packing material.

(*d*) The wood of certain soft species of exogenous trees, after grinding and converting by chemical means into wood-pulp, which is simple cellulose, and similar woods more carefully prepared for the manufacture of artificial silk.

3. *Structural fibres.*

(*a*) Derived from the structural system of the stalks, leaf-stems, and leaves, or other parts of monocotyledonous plants, or inside growers, occurring as isolated fibrovascular bundles, and surrounded by a pithy, spongy, corky, or often a soft, succulent, cellular mass covered with a thick epidermis. They give to the plant rigidity and toughness, thus enabling it to resist injury from the elements, and they also serve as water-vessels.

(*b*) The whole stems, or roots, or leaves, or split and shredded leaves of monocotyledonous plants.

(*c*) The fibrous portion of the leaves or fruits of certain exogenous plants when deprived of their epidermis and soft cellular tissue.

B. SIMPLE CELLULAR STRUCTURE.

4. *Surface fibres.*

(*a*) The down or hairs surrounding the seeds, or seed envelopes, or exogenous plants, which are usually contained in a husk, pod, or capsule.

(*b*) Hair-like growths, or tomentum, found on the surfaces of stems and leaves, or on the leaf-buds of both divisions of plants.

(*c*) The fibrous material produced in the form of epidermal strips from the leaves of certain endogenous species, as the palms.

5. *Pseudo-fibres, or false fibrous material.*

(*a*) Certain of the mosses, as the species of the *Sphagnum,* for packing material.

(*b*) Certain leaves and marine weeds, the dried substance of which forms a more delicate packing material.

(*c*) Seaweeds wrought into lines and cordage.

(*d*) Fungus growths, or the mycelium of certain fungi that may be applied to economic uses, for which some of the true fibres are employed.

The bast fibres * are clearly defined, and all such fibres when simply stripped are similar in form as to outward appearance, differing chiefly in color, fineness, and strength. An example of a fine bast fibre is the ribbons or filaments of hemp. The woody fibres † are only fibrous in the broad sense, as their cellulose is broken down and all extraneous matter removed by chemical means, as for the manufacture of paper-pulp or of artificial silk. The structural fibres ‡ are found in many forms differing widely

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* The bast fibres are derived from the bark of exogeneous plants, such as trees, shrubs, the climbing vines, and herbaceous vegetation generally.

† The greater number of woody fibres are merely wood in the form of flexible slender twigs or osiers that are useful for making baskets; or the larger branches may be split or subdivided into strips, withes, or flat ribbons of wood, for making coarser baskets. The softer woods still further divided give the product known as "excelsior," which can only claim a place in the list of fibres on account of its use in upholstery or packing.

‡ The structural fibres are to be found in many forms, among which may be enumerated the following: The stiff, white, or yellowish fibres forming the structure of all fleshy-leaved or aloe-like plants, as the century plant, the yuccas, agave, and pineapple, or the fleshy trunk of the banana; the coarser bundles of stiff, fibro s substance which gives strength to the trunks, leaf, stem, and even the leaves of palms, such as piassave, derived from the dilated margins of the petioles of a palm; stiff fibres extracted by maceration from the bases of the leaf-stems of the cabbage palmetto, or the shredded leaves of the African fan palm, known as *Crin végétal;* rattan strips and fibrous material derived from bamboo, the corn-stalk, broom-corn, and from reeds, sedges, and grasses; still other forms are the coir fibre surrounding the fruit of the cocoanut, the fibre from pine-needles,

from each other, and the surface fibres * are still more varied in form.

<div align="center">ECONOMIC CLASSIFICATION.†</div>

A. Spinning Fibres.

1. *Fabric fibres.*

(a) Fibres of the first rank for spinning and weaving into fine and coarse textures for wearing apparel, domestic use, or house-furnishing and decoration, and for awnings, sails, etc. (The commercial forms are cotton, flax, ramie, hemp, pineapple, and New Zealand flax.)

(b) Fibres of the second rank, used for burlap or gunny, cotton bagging, woven mattings, floor-coverings, and other coarse uses. (Commercial examples are coir and jute.)

2. *Netting fibres.*

(a) Lace fibres, which are cotton, flax, ramie, agave, etc.

(b) Coarse netting fibres, for all forms of nets, and for hammocks. (Commercial forms: Cotton, flax, ramie, New Zealand flax, agave, etc.)

3. *Cordage fibres.*

(a) Fine-spun threads and yarns other than for weaving; cords, lines, and twines. (All of the commercial fabric fibres,

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and the fibrous mass filling the sponge cucumber, which is a peculiar example of a structural fibre derived from an exogenous plant.

* Surface fibres may consist of the elongated hairs surrounding the pods of the thistle, and known as thistle-down, or they may be fibrous growths around seed clusters, as the cotton-boll, the milk-weed pod, etc., or they may be the leaf scales or tomentum found on the under surface of leaves or epidermal strips of palm leaves, such as raffia.

† Dewey (*Year-Book*, Dept. Agric. 1903) gives the following economic classification of the vegetable fibres:

(1) The cottons, with soft, lint-like fibre $\frac{1}{2}$ inch to 2 inches long, composed of single cells, borne on the seeds of different species of cotton-plants.

(2) The soft fibres, or bast fibres, including flax, hemp, and jute; flexible fibres of soft texture, 10 to 100 inches in length, composed of many overlapping cells and contained in the inner bark of the plants.

(3) The hard, or leaf, fibres, including Manila, sisal, Mauritius, New Zealand fibres, and istle, all having rather stiff, woody fibres 1 to 10 feet long, composed of numerous cells in bundles, borne in the tissues of the leaf or leaf-stem.

sunn, Mauritius, and bowstring hemps, New Zealand flax, coir, Manila, sisal hemps; the fish-lines made from seaweeds.)

(*b*) Ropes and cables. (Chiefly common hemp, sisal, and Manila hemps, when produced commercially.)

B. TIE MATERIAL (*rough twisted*).

Very coarse material, such as stripped palm-leaves, the peeled bark of trees, and other coarse growths used without preparation.

C. NATURAL TEXTURES.

1. *Tree-basts, with tough interlacing fibres.*

(*a*) Substitutes for cloth, prepared by simple stripping and pounding.

(*b*) Lace-barks,* used for cravats, frills, ruffles, etc., and for whips and thongs.

2. *The ribbon or layer basts,* extracted in thin, smooth-surfaced, flexible strips or sheets. (Cuba bast † used as millinery material, cigarette wrappers, etc.)

3. *Interlacing structural fibre or sheaths.*

(*a*) Pertaining to leaves and leaf-stems of palms, such as the fibrous sheaths found at the bases of the leaf-stalks of the cocoanut.

(*b*) Pertaining to flower-buds. The natural caps or hats derived from several species of palms.

D. BRUSH FIBRES.

1. *Brushes manufactured from prepared fibre.*

(*a*) For soft brushes. (Substitutes for animal bristles, such as Tampico.)

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* The lace-bark tree is the *Lagetta lintearia,* and grows principally in Jamaica. The fibre (or rather fabric) is obtained from the inner bark, occurring in concentric layers which are easily detachable, and which are suited to the most delicate textiles; when stretched out they form a pentagonal or hexagonal mesh very closely resembling lace.

† The Cuba bast here referred to is the lace-like inner bark from the *Hibiscus elatus,* which was formerly largely used for tying up bundles of Havana cigars. The plant also yields a bast fibre which is coarse but very strong, and is suitable for the making of cordage and coffee bags.

(*b*) For hard brushes. (Examples: Palmetto fibre, pal-
myra, kittul,* etc.)

2. *Brooms and whisks.*

(*a*) Grass-like fibres. (Examples: Broom-root, broom-
corn, etc.)

(*b*) Bass fibres. (Monkey bass, etc.)

3. *Very coarse brushes and brooms.*

Material used in street-cleaning. Usually twigs and splints.

E, Plaiting and Rough-weaving Fibres.

1. *Used in hats, sandals, etc.*

(*a*) Straw plaits. From wheat, rye, barley, and rice
straw. (Tuscan and Japanese braids.)

(*b*) Plaits from split leaves, chiefly palms and allied forms
of vegetation. (Panama hats.)

(*c*) Plaits from various materials. (Bast and thin woods
used in millinery trimmings.)

2. *Mats and mattings; also thatch materials.*

(*a*) Commercial mattings from Eastern countries.

(*b*) Sleeping-mats, screens, etc.

(*c*) Thatch-roofs, made from tree-basts, palm-leaves,
grasses, etc.

3. *Basketry.*

(*a*) Manufactures from woody fibre.

(*b*) From whole or split leaves or stems.

4. *Miscellaneous manufactures.*

Willow-ware in various forms; chair-bottoms, etc., from
splints or rushes.

F. Various Forms of Filling.

1. *Stuffing or Upholstery.*

(*a*) Wadding, batting, etc., usually commercially pre-
pared lint-cotton.

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* Kittul, or kittool, fibre is obtained from the jaggery palm, *Caryota urens*.
The structural fibre is brownish black in color and lustrous, the filaments being
straight and smooth. It somewhat resembles horse-hair and curls like coir when
drawn between the thumb and nail of the forefinger. In Ceylon the fibre is used
for the manufacture of ropes of great strength which are used for tying elephants.
It is largely used for making brushes of various kinds, especially machine brushes
for polishing linen and cotton yarns, and for brushing velvets.

(*b*) Feather substitutes for filling cushions, etc.; cotton, seed-hairs, tomentum from surfaces of leaves, other soft fibrous material.

(*c*) Mattress and furniture filling; the tow or waste of prepared fibre; unprepared bast, straw, and grasses; Spanish moss, etc.

2. *Caulking.*

(*a*) Filling the seams in vessels, etc.; oakum from various fibres.

(*b*) Filling the seams in casks, etc.; leaves of reeds and giant grasses.

3. *Stiffening.*

In the manufacture of " staff " for building purposes, and as substitutes for cow-hair in plaster; New Zealand flax; palmetto fibre.

4. *Packing.*

(*a*) In bulkheads, etc. Coir, cellulose of corn-pith. In machinery, as in valves of steam-engines; various soft fibres.

(*b*) For protection in transportation; various fibres and soft grasses; marine weeds; excelsior.

G.   PAPER MATERIAL.

1. *Textile papers.*

(*a*) The spinning fibres in the raw state; the secondary qualities or waste from spinning-mills, which may be used for paper-stock, including tow, jute-butts, Manila rope, etc.

(*b*) Cotton or flax fibre that has already been spun and woven, but which, as rags, finds use as a paper material.

2. *Bast papers.*

This includes Japanese papers from soft basts, such as the paper mulberry.

3. *Palm papers.*

From the fibrous material of palms and similar plants. Palmetto and yucca papers.

4. *Bamboo and grass papers.*

This includes all paper material from gramineous plants, including the bamboos, esparto, etc.

5. *Wood-pulp, or cellulose.*

The wood of spruce, poplar, and similar " paper-pulp " woods prepared by various chemical and mechanical processes.

Wiesner gives the following botanical classification of the more important vegetable fibres:

A. VEGETABLE HAIRS.

 1. Cotton (seed-hairs of *Gossypium* sp.).
 2. Bombax cotton (fruit-hairs of *Bombaceæ*).
 3. Vegetable silks (seed-hairs of various *Asclepiadaceæ* and *Apocynaceæ*).

B. BAST FIBRES FROM THE STALKS AND STEMS OF DICOTYLE-DONOUS PLANTS.

(a) *Flax-like fibres.*
 4. Flax (*Linum usitatissimum*).
 5. Hemp (*Cannabis sativa*).
 6. Gambo hemp (*Hibiscus cannabinus*).
 7. Sunn hemp (*Crotalaria juncea*).
 8. Queensland hemp (*Sida retusa*).
 9. Yercum fibre (*Calotropis gigantea*).

(b) *Bœhmeria fibres.*
 10. Ramie or China grass (*Bœhmeria nivea*).

(c) *Jute-like fibres.*
 11. Jute (*Corchorus capsularis* and *C. olitorius*).
 12. Raibhenda (*Abelmochus tetraphyllos*).
 13. Pseudo-jute (*Urena sinuata*).

(d) *Coarse bast fibres.*
 14. Bast fibres from *Bauhinia racemosa*.
 15. Bast fibres from *Thespesia Lampas*.
 16. Bast fibres from *Cordia latifolia*.

(e) *Basts.*
 17. Linden bast (*Tilia* sp.).
 18. Bast from *Sterculia villosa*.
 19. Bast from *Holoptelea integrifolia*.
 20. Bast from *Kydia calycina*.
 21. Bast from *Lasiosyphon speciosus*.
 22. Bast from *Sponia wightii*.

C. Vascular Bundles from Monocotyledonous Plants.

(*a*) *Leaf fibres.*

23. Manila hemp (*Musa textilis* and others of this kind).
24. Pita (*Agave americana* and *A. mexicana*).
25. Sisal (*Agave rigida*).
26. Mauritius hemp (*Agave fœtida*).
27. New Zealand flax (*Phormium tenax*).
28. Aloe fibres (*Aloë* sp.).
29. Bromelia fibres (*Bromelia* sp.).
30. Pandanus fibres (*Pandanus* sp.).
31. Sansevieria fibres (*Sansevieria* sp.).
32. Sparto fibres (*Stipa tenacissima*).
33. Piassave (*Attalea funifera*, *Raphia vinifera*, etc.).

(*b*) *Stem fibres.*

34. Tillandsia fibres, southern moss (*Tillandsia usne-oides*).

(*c*) *Fruit fibres.*

35. Coir or cocoanut fibre (*Cocos nucifera*).
36. Peat fibres.

(*d*) *Paper fibres.*

37. Straw fibres (rye, wheat, oat, rice).
38. Esparto fibres (leaf fibres of *Stipa tenacissima*).
39. Bamboo fibres (*Bambusa* sp.).
40. Wood fibre (pine, fir, aspen, etc.).
41. Bast fibre from paper mulberry (*Broussonetia papy-rifera*).
42. Bast fibre from *Edgeworthia papyrifera*.
43. Peat fibres.

Lecomte (*Textiles végétaux*) gives the following classification with reference to the botany of the textile fibres:

A. Vegetable Hairs.

Cotton.

Asclepias.
Calotropis. } Minor vegetable hair fibres.
Epilobium.
Typha, etc.

B. Bast Fibres.
    I. Dicotyledons.
        a. Urticaceæ family.
            Hemp (*Cannabis*).
            Ramie (*Bœhmeria*).
            Nettle (*Urtica*).
            Paper mulberry (*Broussonetia*).
            Hop (*Humulus*).
        b. Linaceæ family.
            Linen (*Linum*).
        c. Thymeleaceæ family.
            Lace bark (*Lagetta*).
            Nepal paper (*Daphne*).
        d. Tiliaceæ family.
            Jute (*Corchorus*).
            Linden (*Tilia*).
        e. Malvaceæ family.
            Queensland hemp (*Sida*).
            Cæsar weed (*Urena*).
            Pseudo-hemps (*Hibiscus*).
        f. Papilionaceæ family.
            Sunn hemp (*Crotalaria*).
            Clover (*Melilotus*).
            Ginestra (*Genista*).
            Spanish sparto (*Spartium*).
        g. Cordiaceæ family.
            Cordia fibres.
        h. Asclepiadaceæ family.
            Giant asclepias (*Calotropis*).
    II. Monocotyledons.
        a. Gramineæ family.
            Sparto grass (*Stipa*).
            Weeping sylvan (*Lygeum*)
        b. Liliaceæ family.
            New Zealand hemp (*Phormium*).
            Yucca (*Yucca* sp.).
            Bowstring hemps (*Sansevieria*).

    c. Amaryllidaceæ family.
        Sisal hemps (*Agave*).
    d. Bromeliaceæ family.
        Pineapple (*Ananas*).
        Bromelia fibres (*Bromelia*).
    e. Musaceæ family.
        Manila hemp (*Musa*).
    f. Naiadaceæ family.
        Sea wrack (*Zostera*).
    g. Palmæ family.
        Coir (*Cocos*).
        Raffia (*Raphia*).
        Murumuru palm (*Astrocaryum*).
        Crin végétal (*Chamærops*).
        Rattan cane (*Calamus*).
        Sago-palm (*Arenga*).
        Date-palm (*Phœnix*).
        Talipot palm (*Corypha*).
        Oil-palm (*Elæis*).

    3. Physical Structure and Properties.—Seed-hairs, or plumose fibres, are divided into three morphological classes:

    (1) Those consisting of single cells, one end of which is closed and tapers to a point, the other end being broken off abruptly where it is torn from the seed to which it was fastened during growth. This class includes the most important plumose fibres, such as cotton and the vegetable silks.

    (2) Those consisting of a series of cells joined together to form a continuous fibre; this class includes the tomentum or epidermal hair obtained from certain ferns, and are practically valueless as textile materials, though used for upholstery and such purposes.

    (3) Those consisting of several series of cells, represented by the fibres of the so-called *cotton-grass* and *elephant-grass.*

    The hair fibres may originate on almost any organ of the plant exposed to the air. The following table indicates the origin of the majority of such fibres: *

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    * See Lecomte, *Textiles végétaux.*

Hair Fibres.

(1) Covering the seeds, either entirely or in part:

Cotton. . . . .*Malvaceæ.*

Marsdenia
Calotropis
Asclepias   } *Asclepideæ.*
Vincetoxicum
Beaumontia } *Apocyneæ.*
Strophantus
Epilobium. . . . . .*Œnotheraceæ.*

(2) Contained in the flower (rudimentary floral envelope):

Typha. . . . .*Typhaceæ.*
Eriophorum. . . .*Cyperaceæ.*

(3) Lining the interior of the fruit:

Ochroma. . . . .
Bombax. . . . . . . } *Bombaceæ.*
Eriodendron. .

(4) Covering stalks and leaves:

Cibotium. . . . . . .Ferns.

The cell-wall of the plumose fibres in some cases is relatively thin, while in others it is comparatively thick. It is generally without apparent structure, though sometimes it is seen to contain pores, and occasionally a mesh-like interlacing of filaments is observable, especially at the base of the fibre. The inner surface of the cell-wall is usually coated with a cuticle of dried protoplasm, which is evidently similar in constitution to the outer cuticle, as it also remains undissolved when the fibre is dissolved in either concentrated sulphuric acid or an ammoniacal solution of copper oxide. Lecomte * gives the following classification of vegetable fibres with respect to their cellular structure:

1. Fibres consisting of a single isolated cell:

Hairs.	Fibres.
Cotton.	Cottonized ramie and china-grass.
Ascelpias silk	
Bombax cotton.	

* *Textiles végétaux.*

2. Single fibres associated in bundles:
   Unbleached jute.
   Linen (poorly prepared linen frequently contains paren-
   chym cells and epidermal cells).
   Ambari hemp (*Hibiscus*).
   Ramie.
   Hemp (well prepared).
3. Fibres with medullary cells:
   Queensland hemp (*Sida retusa*).
   Cordia latifolia.
   Thespesia lampas.
4. Fibres with parenchym cells:
   Abelmoschus tetraphyllos.
   Urena sinuata.
   Sunn hemp (*Crotalaria juncea*).
   Calotropis gigantea.
   Hemp (as often prepared).

The general term of **bast fibre** includes really two distinct forms; if the fibre occurs in the bast itself it should be designated as true *bast fibre,* such as linen, hemp, and jute. When, however, the fibres do not occur in the bast, but in single bundles in the leaf structure of the plant, they should be designated as *sclerenchymous fibres.* In true bast fibres there are seldom to be noticed distinct pores, whereas the sclerenchymous fibres are abundantly supplied with them. On the other hand, however, the true bast fibres frequently show peculiar dislocations or joints caused by an unequal cell pressure in the growing plant; these are entirely absent in the sclerenchymous fibres. The ends of all bast fibres are usually quite characteristic and exhibit a wide diversity of forms; at times they are sharp-pointed and again blunt; some possess but a single point, while others are split or forked; some-times the cell-wall is thicker than in the rest of the fibre, and sometimes it is thinner. When the cells occur in bundles they are frequently separated from one another by a so-called *median layer,* which forms a sort of matrix in which the separate filaments are imbedded. This layer usually differs in its chemical composition from the cell-wall proper, and gives different color

reactions with various reagents, as it generally consists of lignified tissue. In many cases the cell-walls appear to have a distinct structure, being composed of concentric layers which in cross-section exhibit a stratified appearance.

The bast fibres may be roughly divided into four classes with reference to the comparative sizes of the cell-wall and the inner canal or lumen:

(1) The canal takes up about four-fifths of the diameter of the fibre:

      Ramie and china-grass.

(2) The canal is about two-thirds of the diameter of the fibre:

      Pineapple fibre,

      Hemp,

      Pita and sunn hemp.

(3) The canal is mostly less than one-half the diameter of the fibre:

      Ambari hemp (*Hibiscus*),

      Yucca,

      New Zealand hemp (*Phormium tenax*),

      Manila hemp.

(4) The canal is often reduced to a mere line:

      Linen.

The inner canal is very regular (and consequently the cell-wall will be of uniform thickness) in fibres of yucca, New Zealand hemp, sunn hemp, pita, hemp, linen, ramie, and the plumose fibres. On the other hand, the canal is irregular (with resulting irregularities in the thickness of the cell-wall) in fibres of jute, coir, *Urena sinuata*, *Abelmoschus*, etc.

All plant-cell membranes are doubly refractive towards light, and this is especially true of thick-walled cells which are parallel to the fibre proper. If such a fibre is examined in the dark field of a micro-polariscope it shows a beautiful arrangement of bright prismatic colors.

The degree of double refraction varies with different fibres; in some, as for example in coir, it is very weak, while in others, such as linen and hemp, it is very strong. The following table gives the polarization colors shown by various fibres:

Fibre.	Polarization Colors.
Vascular and parenchy-mous cells of wood and straw..........	Dark gray.
Epidermal cells of straw and esparto.	Dark gray.
Coir	Dark gray.
Cotton.	Dark gray to light gray; also white to yellow.
New Zealand flax	Ditto.
Fibre cells of jute and esparto.............	Dark gray to light gray; yellowish to red.
Bast cells of flax and hemp..............	White, yellowish, orange, red, violet, changing to yellowish white and violet.

In **color** the vegetable fibres vary considerably in the raw state; some, like cotton, ramie, and the vegetable silks, are almost pure white. Others, like linen, possess a grayish-brown color; while others yet, like jute and hemp, have a decided brown color. These colors, however, are due to incrusting impurities, as the cellulose fibres, purified and freed from all such foreign matters, are always white.

In **lustre** the vegetable fibres are usually below those of animal origin, and especially silk, though they differ much in this respect. Cotton probably has the least lustre of any, as its surface is by no means smooth and even, but presents a wrinkled and creased appearance, hence scatters the rays of light reflected therefrom. The other plumose fibres, as the various vegetable silks, have a very smooth surface, and consequently exhibit considerable lustre. Linen, jute, ramie, and the bast fibres in general, when separated into their fine filaments and properly freed from all incrusting matter, possess a rather high degree of lustre; for though they have more or less roughened places and irregularities on their surface, the major portion of such surface is smooth and regular.

The more closely the fibre approximates to pure cellulose the greater becomes its **flexibility** and **elasticity,** and the more it is

lignified * the less these qualities become. That is to say, the highly lignified fibres are stiff and brittle and but little adapted to the spinning of fine yarns.

In **tensile strength** the vegetable fibres vary considerably; owing to the great difference in the physical form and thickness of the various fibres, it is difficult to give a comparison of their respective strengths. The following table gives a comparison between the more important fibres:

Fibre.	Breaking Length in Kilometres.	Tensile Strength, Kilograms per Sq. Millimetre.
Cotton.	23.0	34.27
Linen.	24.0	36.00
Jute.	34.5	49.51
Hemp.	52.0	78.00
Coir.	17.8	
Manila hemp.	31.8	
China grass.	20.0	
Raw silk.	30.8	40.04

The **hygroscopic** moisture contained in vegetable fibres is considerably lower than that present in either wool or silk. While the latter fibres under normal atmospheric conditions will average as much as 12 to 16 per cent. of moisture, cotton and linen will have only from 6 to 8 per cent. The table on page 150 (after Wiesner) gives the amount of moisture in various vegetable fibres in the ordinary air-dry condition, and also the greatest amount they will absorb hygroscopically.

4. **Chemical Composition and Properties.**—Although cellulose forms the chief constituent of all vegetable fibres, it varies much in its purity and associated products in its occurrence in the various fibres. Seed-hairs, like cotton, consist almost entirely of cellulose in a rather pure state, but the bast and vascular fibres always contain more or less alteration products of cellulose, chief among which is ligno-cellulose, or lignin; in fact jute is almost entirely composed of this latter substance. Seed-hairs mostly consist of one single cell to the individual fibre and have very little foreign or incrusting material present. The other

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* The term *lignified* means that the fibre is more or less changed into woody tissue.

HYGROSCOPIC MOISTURE IN VEGETABLE FIBRES.

Fibre.	Air-dry Condition.	Maximum Amount Hygroscopic Water.
Cotton.	6.66	20.99
Flax (Belgian).	5.70	13.90
Jute.	6.00	23.30
China grass.	6.52	18.15
Manila hemp.	12.50	50.00
Sunn hemp.	5.31	10.87
Hibiscus cannabinus.	7.38	14.61
Abelmoschus tetraphyllos.	6.80	13.00
Esparto.	6.95	13.32
Urena sinuata.	7.02	15.20
Piassave *.	9.26	16.98
Sida retusa.	7.49	17.11
Aloe perfoliata.	6.95	18.03
Bromelia karatas.	6.82	18.19
Thespesia lampas.	10.83	18.19
Cordia latifolia.	8.93	18.22
Bauhinia racemosa †	7.84	19.12
Tillandsia fibre.	9.00	20.50
Pita.	12.30	30.00
Calotropis gigantea (bast).	5.67	13.13

fibres are made up of an aggregation of cells bound together in a compact form, and in the cell interstices there is always present more or less gummy and resinous matter, oils, mineral matter, and lignified tissue. All vegetable fibres appear to contain more or less pigment matter, usually of a slight yellowish or brownish color. In ordinary cotton and ramie this coloring matter occurs in only a very small amount and the natural fibre is quite white in appearance. There are some varieties of cotton, however, which are distinctly brown in color. Flax, jute, hemp,

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* Piassave fibre is obtained from a palm-tree, *Attalea funifera*. It is a structural fibre obtained from the dilated base of the leaf-stalks. It is stiff, wiry, and bright chocolate in color, and is principally used in the manufacture of brushes. It is also used on the street-sweeping machines in London. The palm grows principally in Brazil, where the natives use the fibre for making coarse cables which are very durable and so light that they will float on the water.

† The *Bauhinia* is a genus of arborescent or climbing plants found in tropical countries. The fibre is obtained from the bast of the inner bark, and may be made into coarse cordage, but it soon rots in water. The fibre is reddish in color and tough and strong, and has been employed in India for the construction of bridges.

etc., contain a considerable amount of pigment and are of a more or less pronounced brownish color.

Besides cellulose and lignin, there is also present, especially in seed-hairs, a cutose membrane (cork tissue) in the form of an external cuticle. Cutose is insoluble in concentrated sulphuric acid, but is slightly soluble in boiling caustic potash. It doubt-less originates from the plant-wax which is imbedded in the cell. Albuminous matter also occurs in the fibre elements, mostly as a dried tissue which fills the lumen of the fibre more or less com-pletely. It also occurs as a thin film which coats the inner wall of the cell and remains undissolved when the fibre is treated with concentrated sulphuric acid. This membrane exhibits all the reactions of albumin. Silicic acid sometimes is present in vege-table fibres, but only in the walls of the stegmata and in epidermal cells. On ignition the silicious matter is left in almost the original form of the fibre. The silicious skeleton is insoluble in hydrochloric acid, whereas the rest of the ash is readily dissolved by this reagent. Crystals of calcium oxalate occasionally occur in some fibres; they are insoluble in acetic but dissolve in hydro-chloric acid. On ignition of the fibres these crystals are con-verted into calcium carbonate without much change of form, and then are soluble in even very dilute acids.

Woody fibre is to be found in many vegetable fibres, and its presence always lowers the economic value of the fibre. The presence of woody fibre may readily be determined by the appli-cation of a number of characteristic chemical tests. Anilin sulphate, for instance, with woody fibre gives a golden yellow color; phloroglucol with hydrochloric acid gives a red color, phenol with hydrochloric acid a green color, as does also indol with hydro-chloric acid, and a solution of chlor-iodide of zinc gives a brownish yellow color. Woody fibre is also destroyed by the action of alkalies and hypochlorites in the bleaching process; and in fact this process usually has for its chief object the decomposition and removal of the woody fibre which may be present. Due to this fact, certain bleached fibres, such as jute or hemp, may no longer exhibit the above-mentioned color reactions, although they may have done so originally in the raw condition.

There are several reagents which are serviceable in micro-chemical tests on vegetable fibres, as they yield distinctive color reactions.   With the iodin-sulphuric acid reagent * the principal fibres give the following reactions.

(a) *Blue colors:*

Cotton,

Raw fibre from *Hibiscus cannabinus,*
"   "   "   *Calotropis gigantea* (greenish blue to blue),
"   flax fibre,

Cottonized ramie,

Raw sunn hemp (often copper-red),
"   hemp (greenish blue to pure blue).

(b) *Yellow to brown colors:*

Bombax cotton,

Vegetable silk (occasionally greenish or greenish blue),

Raw jute,
"   fibre of *Abelmoschus tetraphyllos,*
"   "   "   *Urena sinuata,*
"   "   "   *Bauhinia racemosa* (blackish brown),
"   "   "   *Thespesia lampas,*
"   esparto (reddish brown),
"   aloe (mostly reddish brown, sometimes greenish and even blue),

New Zealand flax (yellow, green to blue, depending on the purification of the fibre).

The fibres in the second class have their cellulose largely contaminated with lignin, and hence have somewhat of the character of woody tissue.   It is to be remarked, however, that by treatment with nitric acid (or by boiling with caustic potash under pressure) these fibres lose most of the lignin which encrusts their tissues, and then exhibit the characteristics of ordinary cellulose; that is to say, they dissolve in Schweitzer's reagent, and are colored blue with the iodin-sulphuric acid reagent.

Ammoniacal copper oxide † (Schweitzer's reagent) is another

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* For the preparation of this reagent see page 338.
† For the preparation of this reagent see page 337.

reagent which gives characteristic reactions with many vegetable fibres, as follows:

(*a*) *The fibres are almost completely dissolved:**
    Cotton,
    Cottonized ramie,
    Raw fibre of *Hibiscus cannabinus,*
    "   "   " *Calotropis gigantea,*
    "   flax,
    "   hemp (only the bast cells dissolve, the accompanying parenchymous cells remain undissolved),
    "   sunn hemp.

(*b*) *The fibre becomes blue in color and is more or less swollen:*
    Raw jute,
    "   fibre of *Abelmoschus tetraphyllos,*
    "   "   " *Urena sinuata,*
    "   "   " *Bauhinia racemosa,*
    "   "   " *Thespesia lampas,*
    "   New Zealand flax,
    "   fibre of *Aloe perfoliata* (slightly swollen),
    "   "   " *Bromelia karatas* (strongly swollen),
    "   "   " *Sida retusa* (becomes greenish at first, then blue and swells up).

(*c*) *The fibre is colored without swelling:*
    Vegetable silk (blue),
    Bombax cotton (blue),
    Raw esparto (bright green),
    Raw fibre of *Cordia latifolia* (blue),
    "   "   " *Sterculia villosa* (blue).

A solution of anilin sulphate may be used to detect lignification in a fibre; this reagent gives the following color reactions:

(*a*) *The color of the fibre is not changed or but slightly:*
    Cotton,
    Bombax cotton (very slight coloration),
    Cottonized ramie, also the bast cells of raw ramie.

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* With the exception of the external cuticle, the inner cell-wall, and dry protoplasmic residue. For the morphological alterations which the fibres undergo by treatment with this reagent see under the description of the separate fibres.

Raw flax,

Raw bast fibres of *Hibiscus cannabinus* (very slight color-
ation),

Raw bast fibres of *Calotropis gigantea* (very slight colora-
tion),

Raw sunn hemp,

Raw New Zealand flax (very slight coloration),

Manila hemp (very slight coloration),

(b) *The fibre is distinctly or very strongly colored:*

Vegetable silk (intense citron-yellow),

Raw jute (golden yellow to orange),

Raw bast fibres of *Abelmoschus tetraphyllos* (golden yellow),

  "   "   "   " *Urena sinuata* (golden yellow),

  "   "   "   " *Sida retusa* (yellow),

Raw bast fibre of *Thespesia lampas* (golden yellow),

  "   "   "   " *Cordia latifolia* (dull yellow),

Raw hemp (pale yellow),

Raw esparto (sulphur yellow),

Raw fibre of *Bromelia karatas* (golden yellow).

5. Chemical Investigation of Vegetable Fibres.—A chemical
study of the fibres involves an examination of their chemical
constituents. As already stated, though cellulose is the principal
chemical compound to be found in vegetable fibres, yet there
are certain other substances present, which at times may be
characteristic of the fibre. Then, again, the cellulose which
occurs in different classes of fibres appears to be somewhat dif-
ferent in its chemical properties, which has led to the supposition
of different forms of cellulose, already spoken of as ligno-cellulose,
pecto-cellulose, etc. Though the chemistry of these bodies has
been somewhat studied with reference to vegetable fibres by
Cross and Bevan and a few others, yet the subject is still in a
very crude condition, and there is much to be learnt in this field
of chemical research. The methods for the chemical study of
the vegetable fibres adopted by Cross, and continued by other
chemists, may be stated in the following form: A separate
portion of the fibre under examination is taken for each deter-

mination, and the results are calculated into percentages on the dry weight of the substance.

(1) *Moisture.*—This may be called hygroscopic water or water of condition; it is obtained by drying a weighed portion of the fibre at 110° C. to constant weight. If dried at 100° C., about 1 per cent. of the water will be retained. The percentage of hygroscopic moisture in the vegetable fibres varies considerably with the different state of humidity of the surrounding air, on which account it is recommended that the results of the analyses should be expressed on the dry weight of the fibre. It is interesting to note that the contents of hygroscopic moisture in a fibre appears to be an index of the susceptibility of attack by hydrolytic agents, and that the highest class of fibres are distinguished by their relatively low amount of moisture.

(2) *Ash.*—This is taken as the total residue left after ignition of the fibre, and represents the mineral constituents. The proportion of these is low in the ligno-celluloses and higher in the pecto-celluloses, especially when the proportion of non-cellulose is high. Admixture of cellular tissue with the fibre will also raise the amount of ash, as the cellular tissue contains a higher proportion of mineral constituents.

(3) *Hydrolysis.*—This refers to the loss of weight sustained by the fibre (*a*) on boiling for five minutes with a 1 per cent. solution of caustic soda, and (*b*) further loss of weight on continuing to boil for one hour. The first loss in weight represents the proportion of fibre soluble in the alkali, the second represents the proportion of the fibre decomposed by actual hydrolysis. The pecto-celluloses are often so resolved by the action of the dilute alkali that most of the non-cellulose is dissolved away. The amount of hydrolysis of a fibre represents in some measure the power of resistance of a fibre to the action of the boiling-out and bleaching processes, as well as the power of resistance to actual wear as caused by frequent washings with alkalies, soaps, etc.

(4) *Cellulose.*—The determination of the value and composition of the cellulose is made as follows: A sample of the fibre is first boiled for five minutes in a 1 per cent. solution of caustic soda, well washed, and then exposed for one hour at the ordinary

temperature to an atmosphere of chlorin gas; after which it is removed, washed, and treated with an alkaline solution of sodium sulphite, gradually raising to the boil.   After several minutes the fibre is washed, and finally treated with dilute acetic acid, washed, dried, and weighed.   The residue is taken as cellulose, and affords an important criterion as to the composition and value of the raw fibre

(5) *Mercerizing.*—This is represented by the loss in weight sustained by the fibre after treatment for one hour cold with a 33 per cent. solution of caustic potash.   The action of the alkali often causes a considerable change in the structure of the fibre, especially with those fibres made up of a number of fibrils aggregated into bundles.

(6) *Nitration.*—This is represented by the increase in weight sustained by the fibre when treated for one hour with a mixture of equal volumes of nitric and sulphuric acids.   Any change in color is also noted.

(7) *Acid Purification.*—This is represented by the loss in weight sustained by the fibre after boiling with 20 per cent. acetic acid, washing with alcohol and water, and drying.   This treatment is intended to remove from the fibre all accidental impurities with a minimum alteration in composition.

(8) *Carbon Percentage.*—The fibre treated as above (7) is subjected to a combustion in the presence of chromic anhydride and sulphuric acid, and the resulting gas, composed of a mixture of carbon monoxide and dioxide, is collected and measured.   As the two oxides of carbon have the same molecular volume, the amount of carbon in unit volume is independent of the composition of the gas.   The amount of carbon in cotton cellulose (the typical cellulose) is 44.4 per cent.; the compound celluloses, however, have either a lower percentage in the one class (40 to 43 per cent.), or a higher percentage in the second class (45 to 50 per cent.), the pecto-celluloses being included in the first class and the ligno-celluloses in the second class.

CHAPTER IX.

COTTON.

1. Historical.—The use of cotton as a textile fibre dates back to antiquity, mention of it being found in the writings of Herodotus (445 B.C.).* It was used in India, Egypt, and China. The first European country to make cotton goods appears to have been Spain.†

The use of cotton in India dates back to prehistoric times, and it is often referred to as early as 800 B.C. in the ancient laws of Manu.‡ It may be stated that from 1500 B.C. to about the

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* "There are trees which grow wild there (India), the fruit of which is a wool exceeding in beauty and goodness that of sheep. The Indians make their clothes of this tree-wool." (Herodotus, III, 106.) The same writer also refers to the clothing of Xerxes' army as being composed of "cotton fibre." (Herodotus, VII, 65.)

† A rather ambiguous passage in the *Historia Critica de Espana* indicates that the manufacture of linen, silk, and cotton existed in Spain as early as the ninth century. De Marles states that cotton manufacture was introduced into Spain during the reign of Abderahman III., in the tenth century, by the Moors. In the fourteenth century Granada was noted for its manufacture of cotton. A commercial historiographer of Barcelona states that one of the most famous and useful industries of that city was the manufacture of cotton; its workers were united in a guild in the thirteenth century, and the names of two of its streets have preserved the memory of the ancient locality of their shops. There is much uncertainty as to when the manufacture of cotton was first introduced into England; the first authentic record of such is in Robert's *Treasure of Traffic*, published in 1641.

‡ The following quotations are from the *Books of Manu*. The sacrificial thread of the Brahman must be made of cotton (*karpasi*), so as to be put over the head in three strings (*Book II, No.* 44). Let a weaver who has received 10 palas of cotton-thread give it back increased to 11 by the rice-water and the like used in weaving; he who does otherwise shall pay a fine of 12 panas (*Book VIII, No.* 397). Theft of cotton-thread was made punishable by fines of three times the value of the article stolen (*Book VIII, No.* 236).

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same number of years after the Christian era, India was the
centre of the cotton industry, and the cloth which was woven in
a rather crude and primitive manner has rarely been equalled
for fineness and quality.* Cotton was introduced into China
and Japan from India, but its adoption by these countries was
slow.† It was probably introduced into China at the time of
the conquest of this country by the Tartars, but it was not until
about 1300 A.D. that the fibre was cultivated for manufacturing
purposes.‡ In Egypt there is some question as to whether or not
cotton was used except in rather late times, flax being the common
article in that country for the manufacture of cloth. But there is
evidently a good deal of confusion in the early writers respecting
the terms used for "flax" and "cotton," § and it may be that

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* Two Arabian travellers of the middle ages, writing of India, say: "In this
country they make garments of such extraordinary perfection that nowhere else
are the like to be seen; these garments are woven to that degree of fineness that
they may be drawn through a ring of moderate size." (*Anciennes Relations
des Indes et de la Chine*, p. 21.) Marco Polo (*Book III, ch.* 21 *and* 28), about
1298 A.D., mentions India as producing "the finest and most beautiful cottons
that are to be found in any part of the world." Tavernier, in his *Travels*, says
of India that some calicos are made so fine that one can hardly feel them in the
hand, and the thread when spun is scarcely discernible; that the rich have tur-
bans of so fine a cloth that 30 ells of it weigh less than 4 ounces. The poetic
writers of the Orient call these cloths "webs of woven wind." There is the record
of a muslin turban thirty yards in length, contained in a cocoanut set with jewels,
which was so exquisitely fine that it could scarcely be felt by the touch.

† Fesca (*Japanischen Landwirthschaft*, Pt. II, p. 485) says that cotton was
introduced into Japan accidentally in the year 781 A.D. from India, but its cul-
tivation was not continued. Several centuries later it was no doubt introduced again
by the Portuguese; it was not, however, until the seventeenth century, during the
reign of Tokugawa, that the cultivation of cotton became at all general in Japan.
A great deal of cotton is now grown in Korea, having been introduced into that
country from China about 500 years ago. The Korean cotton is of longer staple
and of better quality than the Chinese cotton, as the soil and climate in Korea
is better adapted to its growth.

‡ Marco Polo (*Book II, ch.* 24) gives no account of the culture of cotton in
China, except in the province of Fo-Kien, but speaks of silk as being the custom-
ary dress of the people.

§ Herodotus states that the Egyptian priests wore linen clothes, but Pliny
refers to them as also wearing cotton material, and Philostratus supports this
latter statement. The words translated as "linen" do not always refer to the
fibre of which the cloth was made, but often have reference to the general appearance
of the material; therefore, cloth made from either flax or cotton alone, or mixed,

the ancient Egyptians were better acquainted with the use of
the cotton fibre than we imagine; we at least know that the
cotton plant was grown there at a very early date. The use
of cotton was evidently known to the Greeks * soon after the
invasion of India by Alexander, though this does not signify that
the Greeks themselves either grew the cotton plant or engaged
in the manufacture of the fibre into clothes. The cotton plant
does not appear to have been cultivated in Italy until some time
after the Christian era, although a knowledge of the fibre and a
probable use of the cloth made from it was no doubt known to
them a long time previous.† For the real introduction into
Europe of the cotton plant and the manufacture of the fibre
into cloth we must look to the Mohammedans, who spread this
knowledge throughout the countries bordering on the Mediter-
ranean Sea during the period of their wide-spread conquests.‡
As to the knowledge and use of cotton in the Western Hemisphere,
this seems to also have extended to very early times, for when
Columbus first came to the West Indies in 1492, he found cot-
ton extensively cultivated, and the inhabitants of these islands
wove cloth from the fibre. Among the Mexicans cotton was
found to be the chief article of clothing, as these people did not
possess either wool or silk and were not acquainted with the

was called linen. Even the fact that all Egyptian mummy-cloths so far examined
appear to consist of flax is no argument against the probable use of cotton by
these people; it only proves that flax alone was employed for certain religious
purposes, and cotton, wool, and silk may have been in common use for the cloth-
ing of the people.

* Aristobulus, a contemporary of Alexander, mentions the cotton plant under
the name of the "wool-bearing tree," and states that the capsules of this tree
contain seeds which are taken out, and the remaining fibre is then combed like
wool. (*Strabo, XV,* 1.) Nearchus, an admiral of Alexander, about 327 B.C.,
says: "There are in India trees bearing, as it were, bunches of wool. The natives
made linen garments of it, wearing a shirt which reached to the middle of the
leg, a sheet folded about the shoulders, and a turban rolled around the head. The
linen made by them from this substance was finer and whiter than any other."
(*Arrian. Ind., ch.* 16.)

† Müller (*Handbuch der klas. Alterth. Wissensch.,* vol. **iv,** p. 873) states that
cotton cloth was used for clothing by the Romans prior to 284 A.D.

‡ Abu Zacaria Ebn el Awam, a Moorish writer of the twelfth century, gives
a full account of the proper method of cultivating the cotton plant, and also men-
tions that cotton was cultivated in Sicily.

use of flax, although the plant grew in their country.* In Peru cotton was also in use from an early date, and at the time of Pizarro's conquest of that country in 1522 the inhabitants were clothed in cotton garments; cotton cloths have also been found on Peruvian mummies of a very ancient date. Furthermore, the cotton plant is indigenous to Peru and from it is obtained a special variety known as Peruvian cotton. According to Bancroft, the first attempt towards cotton cultivation in the American colonies was in Virginia, during Wyatt's administration, in 1621. The first mill in the United States for the manufacture of cotton goods appears to have been erected at Beverly, Massachusetts, in 1787. The world's annual consumption of cotton at the present time is about 6,500,000,000 lbs.

2. Origin and Growth.—The cotton fibre consists of the seed-hairs of several species of the genus *Gossypium*, belonging to the natural order of *Malvaceæ.*†

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* Among the presents sent by Cortez to Charles V. of Spain were many fabrics made from cotton.

† The following is a description of the botany of cotton given in *Bulletin No.* 33 of the U. S. Department of Agriculture: " The cotton plant belongs to the *Malvaceæ*, or the mallow family, and is known scientifically by the generic name *Gossypium*. It is indigenous principally to the islands and maritime regions of the tropics, but under cultivation its range has been extended to 40° or more on either side of the equator, or to the isothermal line of 60° F. In the United States latitude 37° north about represents the limit of economic growth. The *Gossypium* plant is herbaceous, shrubby, or arborescent, perennial, but in cultivation herbaceous and annual or biennial, often hairy, with long, simple, or slightly branched hairs, or soft and tomentose, or hirsute, or all the pubescence short and stellate, rarely smooth throughout; stem, branches, petioles, peduncles, leaves, involucre, corolla, ovary, style, capsule, and sometimes the cotyledons more or less covered with small black spots or glands. Roots tap-rooted, branching, long, and penetrating the soil deeply. Stems erect, terete, with dark-colored ash-red, or red bark and white wood, branching or spreading widely. Branches terete or somewhat angled, erect or spreading, or in cultivation sometimes very short. Leaves alternate, petioled, cordate, or subcordate, 3- to 7-, or rarely 9-lobed, occasionally some of the lower and upper ones entire, 3- to 7-veined. Veins branching and netted; the midvein and sometimes adjacent ones bear a gland one-third or ess the distance from their bases, or glands may be wholly absent. Stipules in pairs, linear-lanceolate, acuminate, often ceduous. Flowers pedunculate. Peduncles subangular or angular, often thickened towards the ends, short or very short, erect or spreading; the fruit is sometimes pendulous, sometimes glandular, bearing a leafy involucre. Involucre 3-leaved, or in cultivation some-

The cotton plant is a shrub which reaches the height of four **to** six ft. It is more or less indigenous to nearly all subtropical

FIG. 44.—American Upland Cotton Shrub. (After Dodge.)

countries, though it appears to be best capable of cultivation in warm, humid climates where the soil is sandy, and in the neighbor-

times 4; bracteoles often large, cordate, erect, appressed or spreading at summit, sometimes coalescent at base or adnate to the calyx, dentate or laciniate, sometimes entire or nearly so, rarely linear. Calyx short, cup-shaped, truncate, shortly 5 dentate or more or less 5-parted. Corolla hypogynous. Petals 5, often coalescent at base and by their claws adnate to the lower part of stamen tube, obovate, more or less unequally transversely dilated at summit, convolute in bud. Staminal column dilated at base, arched, surrounding the ovary, naked below, above narrowed and bearing the anthers. Filaments numerous, filiform, simple or branched, conspicuous, exserted. Anthers kidney-shaped, 1-celled, dehiscent by a semicircular opening into two halves. Ovary sessile, simple, 3- to 5-celled. Ovules few or many, in two series. Style clavate, 3- to 5-parted; divisions sometimes erect, sometimes twisted and adhering together, channelled, bearing the stigmas. Capsule more or less thickened, leathery, oval, ovate-

hood of the sea, lakes, or large rivers. It appears to thrive most
readily in North and South America, India, and Egypt; it has

FIG. 45.—Sea-island Cotton Shrub. (After Dodge.)

also been cultivated in Australia, but not as yet with any great
degree of success; inferior qualities have been grown along the

acuminate, subglobose, mucronate, loculicidally dehiscent by 3 to 5 valves. Seed
numerous, subglobose, ovate or subovate, oblong or angular, densely covered
with cotton or rarely glabrous. Fibre sometimes of two kinds, one short and
closely adherent to the seed, the other longer, more or less silky, of single simple
flattened cells more or less spirally twisted, more readily separable from the seed.
Albumin thin, membranous, or none. Cotyledons plicate, auriculate at base
enveloping the straight radicle."

coasts of Africa; that grown in Europe (Italy and Spain) is prac-
tically negligible, as far as commercial considerations are con-
cerned.*   In America, India, and Egypt the cotton plant is annual

* Monie (*The Cotton Fibre*) gives the following account of the cultivation
of the cotton plant: "The plant, although indigenous to almost all warm climates,
is nevertheless only cultivated within a very limited area for commercial pur-
poses, the principal centres of cotton agriculture being in Egypt, the southern
portions of the United States, India, Brazil, the west and southern coasts of Africa,
and the West India Islands. A large amount of white cotton is raised in China,
but this is almost entirely used in the home manufactures. The time when sow-
ing is begun in the different districts varies considerably, being largely dependent
on climatic influences. The seasons, however, are generally as follows: American.—
From the middle of March to the middle of April. Egyptian.—From the begin-
ning of March to the end of April. Peruvian and Brazilian.—From the end
of December to the end of April. Indian or Surat.—From May to the beginning
of August. In the various American plantations the sowing time begins and
ends almost simultaneously, while in other countries, especially where the atmos-
phere and climate are subject to much variation, the period of planting fluctu-
ates; the plants in some parts being several inches above the ground, while in
other parts of the same country the fields may be only under preparation. When
the sowing is finished, and before, and some time after the crop makes its appear-
ance, keeping the ground free from weeds is the main object to be looked to,
otherwise the soil would become much impoverished and the product would
be of an inferior quality. In from eight days to a fortnight after sowing, the
young shoots first appear above ground in the form of a hook, but in a few hours
afterwards the seed end of the stalk or stem is raised out of the ground, disclos-
ing two leaves folded over and closed together. The leaves and stems of these
young plants are very smooth and oily and of a fleshy color and appearance, and,
as before stated, extremely tender (see Fig. 53a). In a short time after the plant
has reached the stage shown in the illustration, it begins to straighten itself and
deepen in color, or, rather, changes to a light oily green, while the two leaves gradu-
ally separate themselves until they attain the forms shown in Fig. 53, *b* and
c. When this stage has been reached its development is rapid, and proceeds in
a similar form to ordinary shrubs until it reaches maturity. In examining the
cotton plant from time to time during its growth some interesting and instruc-
ive objects will be observed. Firstly, in regard to the formation of the leaves,
it will be found that they vary in shape on different parts of the stem. Thus,
for instance, on a Gallini Egyptian (*G. barbadense*) plant the lower leaves were
entire, the centre or middle three-lobed, while the upper leaves were five-lobed.
In the *G. hirsutum* species the lower leaves have five, and some three lobes, with
the small branch petioles of a hairy nature, while the upper leaves are entire
and undivided. In the Peruvian cotton plant the lower leaves are entire and
of an oval shape, while the upper leaves have five acuminated lobes. Another
interesting point observable in the growth of the cotton plant is the presence
of a small cavity situated at the lower end of the main vein under each leaf.
Through this opening, on warm days, the plant discharges any excess of the

in its growth, but in hot tropical climates, and in South America, it becomes a perennial plant and assumes more of a tree-like form. The leaf of the cotton plant has three-pointed lobes;

FIG. 46.—Leaf of the Cotton Plant.

the flower has five petals, yellow at the base, but becoming almost white at the edges. The fruit of the cotton plant forms the cotton

resinous matter which circulates through its branches. Before the plant attains its full height it begins to throw off flower-stalks, which are generally (when perfectly formed) small in diameter and of considerable length; on the extremity of these stalks the blossom pod after a time appears, encased in three leaf-sheaths or calyxes, with fringes of various lengths. Gradually this pod expands until it attains to about the size of a bean, when it bursts and displays the blossom. This blossom only exists in full development for about twenty-four hours, when it begins to revolve imperceptibly on its axis and in about a day's time twists itself completely off. When the blossom has fallen, a small three-, and in some cases, five-celled triangular capsular pod of a dark-green color is disclosed, which increases in size until it reaches that of a large filbert. Meantime the seeds and filaments have been in course of formation inside the pod, and when growth is completed the expansion of the fibre causes it to burst into sections, in each cell of which, and adhering firmly to the surface of the seeds, is a tuft of the downy material."

boll, which contains the seeds with the attached fibres. The boll consists of from three to five segments, and on ripening bursts open * and discloses a mass of pearly white downy fibres (Fig. 49), in which are imbedded the brownish-black to black-colored cottonseeds. The cotton should be picked as soon as possible after ripening; the seeds are then separated from the

Fig. 47.—Leaf and Flower of Sea-island Cotton.
(After *Bulletin No. 33*, U. S. Dept. Agric.)

fibres by a process known as *ginning*. Besides the fibre itself, nearly all of the other products of the cotton are now utilized

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* According to Heuze (*Plantes Industrielles*, vol. 1, p. 139) the time required for the maturity of cotton is divided as follows: From seeding to flowering, New Orleans 80 to 90 days sea-island 100 to 110 days; from flowering to maturity, New Orleans 70 to 80 days, and sea-island about 80 days, making the total period of growth about 5 to 6½ months.

commercially.*   The seeds are of especial value, as they contain a large quantity of oil, which is expressed and used for soap-

FIG. 48.—Leaf and Flower of India Cotton, *Gossypium herbaceum.*
(After *Bulletin No. 33*, U. S. Dept. Agric.)

* According to *Bulletin No. 33* (U. S. Dept. Agric.) the following is the proportion of the different parts of the cotton plant, calculated on the dried or water-free material:

Part of the Plant.	Weight.		Per Cent.
	Ounces.	Grams.	
Roots............................	0.513	14.55	8.80
Stems............................	1.350	38.26	23.15
Leaves...........................	1.181	33.48	20.25
Bolls............................	0.829	23.49	14.21
Seed.............................	1.343	38.07	23.03
Lint (fibre)......................	0.615	17.45	10.56
Total......................	5.831	165.30	100.00

This table was compiled from the examination of a large number of plants and represents the average composition of the cotton plant as stated.

making and many other purposes, while the residuum of meal
and hulls is converted into cattle foods and fertilizer.*   The short
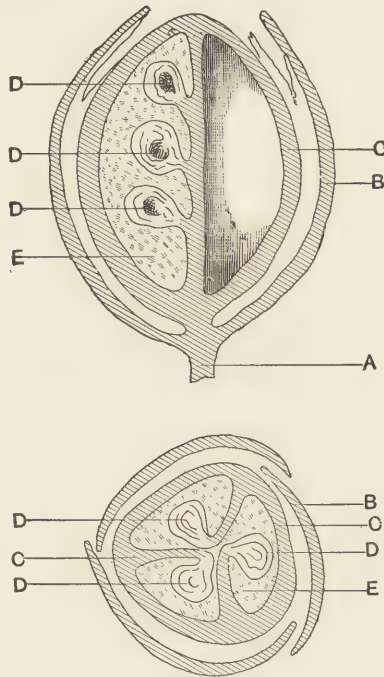
Fig. 49.—Sections of the Cotton Boll (Egyptian).   (After Witt.)
A, stem; *B*, calyx; *C*, capsule; *D*, seed; *E*, cotton fibre.

* The following table presents the fertilizing constituents in a crop of cotton
yielding 100 lbs. of lint per acre, expressed in lbs. per acre.   The weight of
the total crop from the acre was 847 lbs.

Part of Plant.	Nitrogen.	Phosphoric Acid.	Potash.	Lime.	Magnesia.
Roots (83 lbs.).	0.76	0.43	1.06	0.53	0.34
Stems (219 lbs.).	3.20	1.29	3.09	2.12	0.92
Leaves (192 lbs.).	6.16	2.28	3.46	8.52	1.67
Bolls (135 lbs.).	3.43	1.30	2.44	0.69	0.54
Seed (218 lbs.).	6.82	2.77	2.55	0.55	1.20
Lint (100 lbs.).	0.34	0.10	0.46	0.19	0.08
Total (847 lbs.).	20.71	8.17	13.06	12.60	4.75

The following table presents the proximate constitutents of the various

fibres, or nep, left on the seed after the first ginning are also recovered by a second process and are known as *linters*, which are used in the manufacture of cotton-batting, guncotton,* etc. The separation of seed-particles from the fibre is not always perfect, and they frequently make their appearance in gray calico in the form of black specks or motes, and as these contain small quantities of oil and tannin; matters which are pressed out into the surrounding fibres, they cause specks and unevenness in dyeing and finishing. If they come in contact with solutions or materials containing iron compounds, a violet stain will be produced, the color of which, however, may not develop for some months.

Bowman (*loc. cit.*) gives an excellent description of the physiological development of the cotton fibre,† from which the

parts of the cotton plant as given by analyses of a large number of samples by the United States Department of Agriculture:

Part of Plant.	Water.	Ash.	Protein.	Fibre.	Nitrogen-free Extract.	Fat.
Entire plant.........	10.00	12.01	17.57	22.04	35.11	4.15
Roots..............	10.00	7.23	9.89	48.57	39.15	2.77
Stems..............	10.00	9.64	20.45	49.44	39.87	3.50
Leaves.............	10.00	12.87	21.64	12.57	36.82	6.05
Bolls..............	10.00	4.90	15.89	19.72	45.42	4.07
Seed..............	9.92	4.74	19.38	22.57	23.94	19.45
Lint..............	6.74	1.65	1.50	83.71	5.79	0.61

* With sea-island and Egyptian cottons the seed is entirely freed from lint by ginning, but with upland cottons the quantity of lint still adhering to the seed after it has passed through the gin amounts to about 10 per cent. of the total weight of the seed. An Experiment Station Report shows that the seeds from upland cotton after ginning consist of 54.22 per cent. of kernels (yielding 36.88 per cent. of oil and 63.12 per cent. of meal) and 45.78 per cent. of hulls (yielding 27.95 per cent. of linters and 72.05 per cent. residue); so that in the ginned seed is present the following:

Meal............................... 34.22 per cent.
Oil................................. 20.00　"　"
Hulls............................... 35.78　"　"
Linters............................. 10.00　"　"

According to Adriane (*Chem. News*, Jan., 1865) the seeds fom Egyptian cotton yield 37.45 per cent. of hulls and 62.55 per cent. of kernels.

† The following remarks relative to the development of the cotton fibre from the seed are taken from *Bulletin No. 33 (vide supra):* "If a very immature

following is quoted: "In their earliest stages the young cotton fibres appear to have a circular section arising from the comparative thickness of the tube-walls; but as these walls gradually become thinner by the longitudinal growth of the hair and the pressure to which they are subjected by the contact of surrounding fibres enclosed within the pod, they gradually become flat-
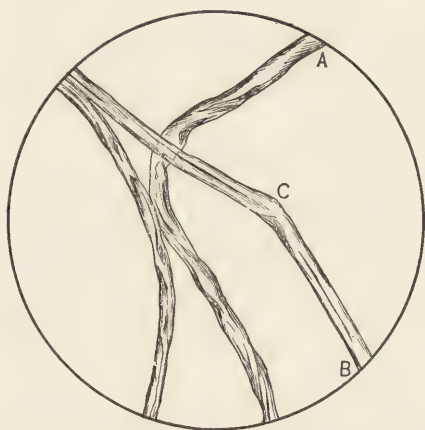
FIG. 50.—Typical Cotton Fibres. (×300.) *A*, normal fibre showing regular twists; *B*, straight fibre without twists; *C*, a knot or irregularity in growth of fibre. (Micrograph by author.)

tened, and just before the pod bursts the outer walls of the cells have become so attenuated in the longest fibres as to be almost invisible even under high microscopic powers, and present the

cotton boll be cut transversely, the cut section will show that it is divided by longitudinal walls into three or more divisions, and the seeds will be shown attached to the inner angle of each division. The seeds retain this attachment until they have nearly reached their mature size and the growth of lint has begun on them, when their attachments begin to be absorbed, and by the increased growth of the lint the seeds are forced into the centre of the cavity. The development of the fibre commences at the end of the seed farthest from its attachment and gradually spreads over the seed as the process of growth continues. The first appearance of the cotton fibre occurs a considerable time before the seed has attained its full growth and commences by the development of cells from the surface of the seed These cells seem to have their origin in the second layer of cellular tissue, and force themselves through the epidermal layer, which seems to be gradually absorbed The cells which originate the fibre are characterized by the thickness of their cell-walls when compared with their diameter."

appearance of a thin, pellucid, transparent ribbon. With the bursting of the pod, however, a change occurs. The admission of air and sunlight causes a gradual unfolding of the hairy plexus, and the rapid consolidation of the liquid cell-contents on the inner surface of the cell-wall gives them a greater thickness and density, which is further increased by the gradual shrinking-in of the walls themselves upon the cell-contents. There is also a gradual rounding and thickening of the fibre, which increases by the deposition of matter on the inner wall of the cell.
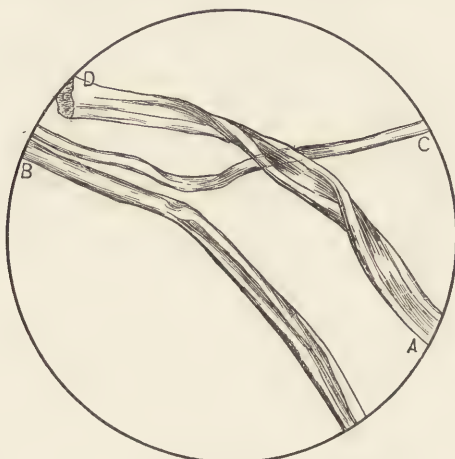
FIG. 51.—Typical Cotton Fibres. (× 300.) *A*, broad flat fibre near base; *B*, thick rounded fibre; *C*, fibre near pointed end; *D*, cut end of fibre. (Micrograph by author.)

As this action is not perfectly uniform, arising from the unequal exposure of different parts of the fibres to light and air, it causes a twisting of the hairs, which is always a characteristic of cotton when viewed under the microscope, and the flat collapsed portions of the tube form so many reflecting surfaces, to which the brightness of the fibre when stretched tight in the fingers is no doubt due. Another change also occurs at this stage, a change which corresponds to the ripening of fruit. In the earliest period of their formation the growing cells are filled with juices which are more or less astringent in character. Under the influence of light and air these cell contents undergo a chemical change,

in which the astringent principles are replaced by more or less saccharine or neutral juices, until in the perfectly ripe cotton fibre the cell-walls are composed of almost pure cellulose."

The cell-wall of the cotton is thin in comparison with that of the bast fibres, but in comparison with the other seed-hairs it is remarkably thick. This accounts for its much greater strength over the latter. In completely developed fibres the thickness of the cell-wall is from one-third to two-thirds of the total thickness of the fibre itself.

The quality of the cotton fibre depends not only on the species of the plant from which it is derived, but also on the manner

Fig. 52.—Cotton Bolls.

of its cultivation. The conditions which exercise, perhaps, the greatest influence are: (a) the seed, (b) the soil, (c) the mode of cultivation, (d) the climatic conditions.* The seed for sowing must be carefully and specially chosen for the purpose. A

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* It is said that the best average daily temperature for the growth of cotton is from 60° to 68° F. for the period from germination to flowering, and from 68° to 78° F. from flowering to maturity. According to Dr. Wight (*Jour. Agr. Hort. Soc. India*, vol. 7, p. 23), for the proper maturing of the best qualities of American cotton an increasing temperature during the period of greatest growth is required; the failure to produce in India a quality of fibre equal to the American product from the same kind of seed is attributed to the fact that in the climate of the former country there exists a diminishing rather than an increasing average daily temperature.

very dry soil produces harsh and brittle cotton, the fibres of
which are very irregular in length; a moist and sandy soil pro-
duces a very desirable cotton of long and fine staple.*   The best
soil is considered to be a light loam, while a damp clay is regarded
as the worst.   Soils situated in proximity to the sea, and there-
fore containing considerable saline matter, appear _ to furnish
the most valuable varieties of cotton, and it is claimed that the

a   *b*   *c*

FIG. 53.—The Cotton Plant in the Early Stages of its Growth.

saline constituents of the soil have considerable influence on
the growth and development of the cotton fibre.

  3. Varieties of Cotton.†—The classification of the different

* An excess of rain causes the plant itself to grow too rapidly and luxuriantly
at the expense of the fruit and consequently there is less fibre produced.   A long
drought causes a stunted growth of the plant, but few bolls are produced, and
these ripen prematurely.

  † The various names given to the cotton fibre in different countries may be
of interest; they are as follows:

India	Pucü
Spain	Algodon
Yucatan and ancient Mexico	Ychcaxihitvitl
Tahiti	Vavai
France	Coton
Italy	Cotone
Germany	Baumwolle
Persia	Pembeh or Poombeh
Arabia	Gatn, Kotan, or Kutn
Cochin China	Cay Haung
China	Hoa mein
Japan	Watta ik or Watta noki
Siam	Tonfaa
Hindoostan	Nurma
Mysore and Bombay	Deo Kurpas and Deo Kapas
Mongolia	Kohung

species of cotton plant varies with different authorities; the most comprehensive, perhaps, is to classify the different varieties of the cotton plant as (1) the tree, (2) the shrub, and (3) the herbaceous species.*   According to Parlatore all commercial cotton

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* The following is a list of species of the cotton plant more or less recognized by botanists:

Gossypium album Hamilton, a synonym of *G. herbaceum;* commercially known as upland cotton; has a white seed.

G. arboreum Linn., a tree-like plant; perennial; indigenous to India; produces but little fibre.

G. barbadense Linn., indigenous to America and outlying islands; gives the highly prized sea-island cotton.

G. brasiliense Macfad., a tropical species; belongs to the so-called "kidney cottons"; the seeds adhere to one another in clusters.

G. chinense Fisch. & Otto, a synonym for *G. herbaceum;* a Chinese cotton.

G. croceum Hamilton, a synonym for *G. herbaceum;* possesses a yellow lint.

G. eglandulosum Cav., a synonym for *G. herbaceum.*

G. elatum Salisb., a synonym for *G. herbaceum.*

G. fructescens Lasteyr., a synonym for *G. barbadense.*

G. fuscum Roxb., a synonym for *G. barbadense.*

G. glabrum Lam., a synonym for *G. barbadense.*

G. glandulosum Steud., a synonym for *G. herbaceum.*

G. herbaceum Linn., usually considered of Asiatic origin; synonymous with *G. hirsutum;* ordinary upland cotton.

G. hirsutum Linn., of American origin; Georgia upland cotton.

G. indicum Lam., a synonym for *G. herbaceum.*

G. jamaicense Macfad., a synonym for *G. barbadense;* grows in Jamaica.

G. javanicum Blume, a synonym for *G. barbadense;* grows in Java.

G. latifolium Murr., a synonym for *G. herbaceum.*

G. leonivum Medic., a synonym for *G. herbaceum.*

G. macedonicum Murr., a synonym for *G. herbaceum.*

G. maritimum Tod., a synonym for *G. barbadense.*

G. micranthum Cav., a synonym for *G. herbaceum.*

G. molle Mauri, a synonym for *G. herbaceum.*

G. nanking Meyen, a synonym for *G. herbaceum*

G. neglectum Tod., indigenous to India; similar to *G. aboreum;* extensively grown in India; gives the Dacca and China cottons.

G. nigrum Hamilton, a synonym for *G. barbadense.*

G. obtusifolium Roxb., a synonym for *G. herbaceum.*

G. oligospermum Macfad., a synonym for *G. barbadense.*

G. paniculatum Blanco, a synonym for *G. herbaceum.*

G. perenne Blanco, a synonym for *G. barbadense.*

G. peruvianum Cav., a synonym for *G. barbadense.*

G. punctatum Schum. & Thonn., a synonym for *G. barbadense.*

G. racemosum Poir, a synonym for *G. barbadense.*

G. religiosum Par., a synonym for *G. arboreum;* so called because its use is

is derived from seven species of the *Gossypium*, which he
enumerates as follows: *

  (1) *G. barbadense*,† which comprises the long-stapled and

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mostly restricted to making turbans for Indian priests; also because it
grows in the gardens of the temples; it has the cultural name of Nurma
or Deo cotton. Also a variety of *G. barbadense.*

G. roxburghianum Tod., a variety of *G. neglectum;* corresponds to the Dacca
cotton of India.

G. siamense Tenore, a synonym for *G. herbaceum.*

G. sinense Fisch., a synonym for *G. herbaceum.*

G. stocksii Masters, a synonym for *G. herbaceum;* claimed to be the original
of all cultivated forms of this latter species.

G. strictum Medic., a synonym for *G. herbaceum.*

G. tomentosum, indigenous to the Hawaiian Islands; the bark is used for
making twine.

G. tricuspidatum Lam., a synonym for *G. herbaceum.*

G. vitifolium Lam., a synonym for *G. barbadense.*

G. vitifolium Roxb., a synonym for *G. herbaceum.*

G. wightianum Tod., a synonym for *G. herbaceum;* claimed by Todaro to be
the primitive form of the Indian cottons.

* Filippo Parlatore, *Le specie dei cotoni,* 1866.

† The botany of this species is given as follows: Shrubby, perennial, 6 to 8 feet
high, but in cultivation herbaceous and annual or biennial, 3 to 4 feet high, gla-
brous, dotted with more or less prominent black glands. Stems erect, terete,
branching. Branches graceful, spreading, subpyramidal, somewhat angular,
ascending, at length recurving. Leaves alternate, petiolate, as long as the petioles,
rotund, ovate, subcordate, 3- to 5-lobed, sometimes with some of the upper and
lower leaves entire, cordate, ovate, acuminate; lobes ovate, ovate-lanceolate,
acute or acuminate, channelled above, sinus subrotund, above green, lighter on
the veins, glabrous, beneath pale green and glabrous, 3- to 5-veined, the mid-
vein and sometimes one or both pairs of lateral veins bearing a dark-green gland
near their bases. Stipules erect or spreading, curved, lanceolate-acuminate,
entire or somewhat laciniate. Peduncles equal to or shorter than the petiole,
erect, elongating after flowering, rather thick, angled, sometimes bearing a large
oval gland below the involucre. Involucre 3-parted, erect, segments spreading
at top, many veined, broadly cordate-ovate, exceeding half the length of the
corolla, 9 to 12 divided at top, divisions lanceolate-acuminate. Calyx much
shorter than the involucre, bracts cup-shaped, slightly 5-toothed or entire. Corolla
longer than the bracts. Petals open, but not widely expanding after flower-
ing, broadly obovate, obtuse, crenate, or undulate margined, yellow or sulphur
colored, with a purple spot on the claw, all becoming purplish in age. Stamen
about half the length of the corolla, the tube naked below, anther bearing above.
Style equal to or exceeding the stamens, 3 to 5 parted. Ovary ovate, acute, glandu-
lar, 3-, rarely 4- to 5-celled. Capsule a little longer than the persistent involucre,
oval, acuminate, green, shining, 3-, rarely 4- to 5-valved. Valves oblong or ovate-
oblong, acuminate, the points widely spreading. Seeds 6 to 9 in each cell, obovate,

silky-fibred cottons known as *Barbadoes, sea-island, Egyptian,* and *Peruvian.* The plant reaches a height of from 6 to 8 feet, and has yellow blossoms. Owing to variations in the conditions of its cultivation, however, the present sea-island cotton has changed considerably from the original *barbadense.** This variety is employed for the spinning of fine yarns, such as are known in trade as "Bolton counts."

(2) *G. herbaceum,*† including most of the cotton from India,

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narrowed at base, black. Fibre white, 3 to 4 or more times the length of the seed, silky, easily separable from the seed. Cotyledons yellowish, glandular, punctate.

* The following species are considered as synonyms of *G. barbadense: G. fructescens* Lasteyr., *G. fuscum* Roxb., *G. glabrum* Lam., *G. jamaicense* Macfad., *G. javanicum* Blume, *G. maritimum* Todaro, *G. nigrum* Ham., *G. oligospermum* Macfad , *G. perenne* Blanco, *G. peruvianum* Cav., *G. punctatum* Schum. & Thonn, *G. racemosum* Poir., *G. religiosum* Par., and *G. vitifolium* Roxb.

† The descriptive botany of this species is as follows: Shrubby, perennial, but in cultivation herbaceous, annual or biennial. Pubescence variable, part being long, simple or stellate, horizontal or spreading, sometimes short, stellate, abundant, or the plants may be hirsute, silky, or all pubescence may be more or less wanting, the plants being glabrous or nearly so. Glands more or less prominent. Stems terete, or somewhat angular above, branching. Branches spreading or erect. Leaves alternate, petioled, the petioles about equalling the blades, cordate or subcordate, 3- to 5-, rarely 7-lobed. Lobes from oval to ovate, acuminate, pale green above, lighter beneath, more or less hairy on the vein, 3- to 5- o 7-veined, the midvein and sometimes the nearest lateral veins glandular towards the base or glands wanting. Sinus obtuse. Lower leaves sometimes cordate, acuminate, entire, or slightly lobed. Stipules erect or spreading, ovate-lanceolate to linear-lanceolate, acuminate, entire, or occasionally somewhat dentate. Peduncles erect in flower, becoming pendulous in fruit. Involucre 3-, rarely 4-parted, shorter than the corolla, appressed, spreading in fruit, broadly cordate, incisely serrate, the divisions lanceolate-acuminate, entire or sometimes sparingly dentate. Calyx less than half the length of the involucre cup-shaped, dentate, with short teeth. Petals erect, spreading obovate or cuneate, obtuse or emarginate, curled or crenulate, white or pale yellow, usually with a purple spot near the base, in age becoming reddish. Stamens half the length of the corolla. Pistil equal or longer than the stamens. Ovary rounded obtuse or acute, glandular, 3- to 5-celled. Style about twice the length of the ovary, 3- to 5-parted above, the glandular portion often marked with 2 rows of glands. Capsule erect, globose or ovate, obtuse or acuminate, mucronate, pale green, 3- to 5-celled. Valves ovate to oblong, with spreading tips. Seed 5 to 11 in each cell, tree, obovate to subglabrous, narrowed at base, clothed with two forms of fibre, one short and dense, closely enveloping the seed, the other 2 to 3 times the length of the seed, white, silky, and separating with some difficulty. Cotyledons somewhat glandular, punctate.

southern Asia, China, and Italy.*   It is an annual plant growing
from 5 to 6 feet in height; unlike the *barbadense* variety, its seeds
are generally covered with a soft undergrowth of fine down,
which is an objectionable feature.   The flower is yellow in color.
This species is perhaps the hardiest of the cottons, and is cultivated
over a wider range of latitude.†   It forms the source of nearly all
the Indian cotton.‡   It is used for the spinning of low-count

* Parlatore claims that this species originated in India, while Todaro says
that it is spontaneous in Asia and perhaps also in Egypt, and that *G. wightianum*
is the primitive form of the Indian cottons; others still consider it as a native
of Africa.   According to *Bulletin No. 33* (U. S. Dept. Agric.), it is probable that
G. herbaceum is not a definite species, but has been developed by cultivation
from perhaps several wild species, and it represents not a species but a group of
hybrids and forms more or less closely related.

† The following species are considered as synonyms of *G. herbaceum*: *G. album*
Ham., *G. chinense* Fisch., *G. croceum* Ham., *G. eglandulosum* Cav., *G. elatum*
Salis., *G. glandulosum* Steud., *G. hirsutum* Linn., *G. indicum* Lam., *G. latifolium*
Murr., *G. leoninum* Medic., *G. macedonicum* Murr., *G. micranthum* Cav., *G. molle*
Mauri, *G. nanking* Meyen, *G. obtusifolium* Roxb., *G. paniculatum* Blanco, *G. punc-
tatum* Guil., *G. religiosum* Linn., *G. siamense* Tenore, *G. sinense* Fisch., *G. stric-
tum* Medic., *G. tricuspidatum* Lam., and *G. vitifolium* Roxb.

‡ Todaro claims that the species *G. wightianum* is the form chiefly cultivated
in India.   It differs from the general form of *G. herbaceum* in that the latter has
broader and more rounded leaves, and broader, thinner, and deeper cut brac-
teoles.   The botany of *G. wightianum* is as follows: Stems erect, somewhat
hairy, branches spreading and ascending.   Leaves, when young, densely covered
with short thick, stellate hairs, becoming nearly glabrate in age; ovate-rotund,
scarcely cordate, 3- to 5-, rarely 7-lobed; lobes ovate, oblong, acute, constricted
at base into a rounded sinus.   Stipules on the peduncles almost ovate, others
linear-lanceolate, acuminate.   Flowers yellow with a deep purple spot at base,
becoming reddish on the outside in age.   Bracteoles small, slightly united at
base, ovate, cordate, acute, shortly toothed.   Peduncles erect in flower, recurved
in fruit, one-quarter the length of the petioles.   Capsule small, ovate, acute,
4-celled, with 8 seeds in each cell.   Seeds small, ovate, subrotund, clothed with
two forms of fibre, the inner short and closely adhering, the other longer, white
or reddish.

There is another very similar form indigenous to India known as *G. neglectum*,
it grows as a large bush, and its fibre constitutes the majority of the commer-
cial Bengal cotton.   Its botany is as follows: Stem erect.   Branches slender,
graceful, spreading.   Leaves, lower ones 5 to 7 palmately lobed, segments lanceo-
late, acute, rarely bristle-tipped, sinus rounded, the small lobes in the sinuses
less distinct than in *G. arboreum*, upper leaves 3-parted.   Stipules next the ped-
uncles semiovate, dentate, the others linear-lanceolate, acute.   Peduncles, with
short lateral branches, 2 to 4 flowered.   Involucral bracts coalescent at base,
deeply and acutely laciniate.   Petals less than twice the length of the involucral

yarns, also for the making of condenser yarns for the manufacture of flannelettes.

(3) *G. hirsutum,** including most of the cotton from the southern United States, also known as *upland* cotton. The plant is shrubby in appearance, seldom reaching more than 7 feet in height; like the preceding variety, the seeds are also covered with a fine undergrowth of down.

(4) *G. arboreum,*† including the cotton from Ceylon, Arabia,

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bracts, obovate, unequally cuneate, yellow, with a deep purple spot at base. Stamen-tube half the length of the corolla, naked at base. Capsule small, ovate, acute, cells 5- to 8-seeded, seed obovate, small, clothed with two forms of fibre, one very short, closely adherent, and of an ashy green color, the other longer, rather harsh, white.

* Todaro claims that this species originated in Mexico, whence it has been spread by cultivation throughout the warmer portions of the world; to this form he also ascribes the Georgia or long-stapled upland cotton. Parlatore, on the other hand, considers it as indigenous to the islands in the Gulf of Mexico as well as the mainland, and that all green-seeded cotton, wherever cultivated, originated from this form.

† The descriptive botany of this species is as follows: Shrubby, perennial, but in cultivation sometimes annual or biennial; tomentose, with two forms of hairs, one long and simple, the other more numerous, shorter, and stellate; glands small, scarcely prominent, more or less scattered. Stem erect, terete, very branching. Branches spreading, terete. Leaves alternate, petiolate, with petioles a little shorter than the blade, subcordate, 5- to 7-lobed, lobes oblong-lanceolate or lanceolate-acuminate, bristle-tipped, scarcely channelled above; sinus obtuse, often with a small lobe in some of the sinuses, beneath pale green and softly pubescent, 5- to 7-veined, the midvein and often the two adjacent ones with a reddish-yellow gland near their base; upper leaves palmately 3- to 5-lobed, lobes short. Stipules erect, spreading, lanceolate-acuminate. Peduncles axillary, erect before and spreading or horizontal after flowering and drooping in fruit, about three-fourths the length of the petioles, terete, destitute of glands, 1 to 2 usually 1-flowered, jointed above the middle, bearing a small leaf and two stipules at this point. Involucre three-parted, appressed or scarcely spreading at summit, many nerved, broadly and deeply cordate, ovate-acuminate, 5 to 9, rarely 3 dentate or nearly entire. Calyx much shorter than the bracts, subglobose, truncate, crenulate or subdentate, with a large gland at the base within the involucre. Corolla campanulate, petals erect or spreading, broadly cuneate, subtruncate, crisp or crenulate, purple or rose-colored, with a large dark purple spot at the base. Staminal tube about half the length of the corolla. Pistils equally or a little longer than the stamens. Ovary ovate, acute, glandular, usually 3-celled. Style a little longer than the ovary, 3-parted without glands. Capsule pendulous, a little longer than the persistent involucre, ovate, rounded, glandular, 3- to 4-celled, and valved. Valves ovate, oval, spreading, mucronate-

etc. As the name indicates, it is a tree-like plant, and grows from 12 to 18 feet in height. The fibres are of a greenish color and very coarse; its flowers are of a reddish color.*

(5) *G. peruvianum,* including the native Peruvian and Brazilian cottons. This differs from other varieties of cotton in that it is a perennial plant; the growth from the second and third years, only, however, is utilized.

(6) *G. tahitense,* found chiefly in Tahiti and other Pacific islands.

(7) *G. sandwichense,* occurring principally in the Hawaiian Islands.

This classification is claimed to include all the commercial varieties of cotton; it is probable, however, that the last two can be included under the *barbadense* and *hirsutum* varieties, as they possess the same characteristics as these fibres.†

Other authorities on the botany of the cotton plant have recognized many more species than those above described. Agostino Todaro ‡ has described 52 varieties, while the *Index Kewensis* § records 42 distinct species and refers to 88 others which it classifies as synonyms. Hamilton reduces the number of species to three, namely, the white-seeded, black-seeded, and yellow-linted, assigning to these species the botanical names *album,* *nigrum,* and *croceum.* The chief difficulty experienced in the botanical classification of the cotton plant is the fact that it hybridizes § very readily and has a tendency to suffer alteration

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acuminate, the mucro recurved. Seed 5 to 6, ovate, obscurely angled, black. Fibre two forms, one white, long, overlying a dark green or black down; not readily separable from the seed.

* A synonym of this species is *G. religiosum;* it appears to be indigenous to India. The plant is perennial and lasts from five to six years, and though the fibre is fine, silky, and of good length, yet there is but little of it produced.

† Dr. Royle reduces the number of species of the cotton plant to the following four:

(1) *Gossypium arboreum.*
(2)   "   *herbaceum.*
(3).   "   *barbadense.*
(4)   "   *hirsutum.*

‡ *Rel. sulla coltura dei cotoni in Italia,* 1877–78, vol. 2, pp. 1057 and 1058.

§ *Bulletin No. 33 (vide supra)* makes the following remarks relative to the subject of the cross-fertilization of cotton. The flower of the cotton plant is so large

in variety with change in the conditions of its cultivation or variation in the character of the soil or climate.*

Besides the varieties of cotton above enumerated, which are practically all which find any important commercial application, there is another plant which yields a fibre somewhat similar to cotton, and known as the silk-cotton plant. It belongs to the same natural order, *Malvaceæ*, as the ordinary cotton plant, but is of a different genus, being *Salmalia* instead of *Gossypium*. It grows principally on the African coast and in some parts of tropical Asia. The plant is rather a large tree, reaching from 70 to 80 feet in height. The blossoms are red in color, and the seeds are covered with long silky fibres, which are not adapted, however, for spinning.

Although fibres from the different species of the cotton plant all possess the same general physical appearance, nevertheless,

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and develops so rapidly that cross-fertilization is easily secured. Flowers which are to be fertilized should be among those which are developed early in the season, and should always be those on healthy and vigorous plants. The flowers to be operated upon should be selected late in the afternoon; one side of the unopened bud should be split lengthwise with a sharp knife having a slender blade, and the stamens removed. The anthers, the fertilizing parts of the stamens, will be found well developed and standing well away from the pistil, though not yet so matured as to be discharging pollen. These can be readily separated from their support by a few careful strokes of the knife, and the emasculated flower should then be enclosed in a paper bag to prevent access of pollen from unknown sources. The following morning the pistil will be fully developed and ready to receive pollen. A freshly opened flower from a healthy plant of the variety which it is desired to use in making the cross is picked and carried to the plant which was treated the previous evening, the bag is removed from the prepared flower, and by means of a camel-hair brush pollen is dusted over the end and upper part of the pistil. The paper bag is then replaced and allowed to remain two days, after which it should be removed.

* In Europe cottons are graded according to their value as follows:

1. Long Georgia.
2. Makko.
3. Pernambuco.
4. Louisiana.
5. Cayenne.
6. New Orleans.
7. Short Georgia.
8. Surat.
9. Bengal.

there are characteristic features in each worthy of careful observation.

Gossypium barbadense: Sea-island. — This constitutes the most valuable, perhaps, of all the different species. Its chief points of superiority are (*a*) its length, being more than half an inch longer than the average of other cottons; (*b*) its fineness of staple; (*c*) its strength; (*d*) its number of twists, which allow it to be spun to finer yarns; (*e*) its appearance, it being quite soft and silky. It is also characterized by a light-cream color. Sea-island cotton is mostly used for the production of fine yarns ranging from 120's to 300's;* it is said that as fine as 2000's has been spun from it.† On account of its adaptability for mercerizing it is also largely employed for this purpose, in which case much coarser yarns are often prepared from it. Owing to the wide cultivation of sea-island cotton at the present time, for its growth is no longer strictly confined to the islands of the sea,‡ it is difficult to make a definite statement as to its length of staple, as this will vary considerably with the method and place of cul-

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* The "count" of cotton yarn means the number of hanks of 840 yards each contained in 1 lb. The size 120's, for instance, means cotton yarn of such fineness that 120 hanks of 840 yards (= 100,800 yards) weigh 1 lb. The French method of numbering is based on the decimal system, and the count means the number of hanks each 1000 meters in length required to weigh 500 grams. In order to change from French to English count, multiply the former by 0.847, or $\frac{17}{20}$. The Belgian method of counting is to use the number of 840-yard hanks in 500 grams. The Austrian system is the number of hanks of 950 ells each contained in 500 grams. The English system is the one mostly used, being employed in England, America, India, Germany, Italy, and Switzerland, and even in parts of Austria. Doubled or twisted yarns are designated in the same manner as single yarns, except that the number of threads is also given, for instance, if two single threads of count 20 are twisted together, the yarn is described as 2–20's or $\frac{2}{20}$, or $\frac{20}{2}$; a three-ply yarn would be 3–20's, or $\frac{9}{20}$ or $\frac{20}{3}$, etc. According to the number of threads twisted together, yarns will lose from 2.5 to 6 per cent. of their length in doubling, and, of course, become correspondingly thicker. Yarns containing more than two single threads are known as sewing twist or cord.

† See Monie, *Structure of the Cotton Fibre*, p. 40, as authority for this statement. A thread of such fineness would not be commercial, and has never been prepared, except, perhaps, in an experimental manner.

‡ Some writers claim that sea-island cotton is peculiarly of American origin; that it was found on the island of San Salvador by Columbus, and by him brought to Spain. Other writers, among whom is Masters (*Jour. Linn. Soc.*, vol. 19, p. 213), assert that this cotton is of central African origin.

tivation.* The maximum length, however, may be taken as 2 inches, and the minimum as $1\frac{5}{8}$ inches, with a mean of $1\frac{3}{4}$ inches. *Florida sea-island* cotton is very similar in general characteristics to sea-island proper, possessing about the same mean length of staple, but being somewhat less in the maximum length.† Both of these varieties of sea-island show a maximum diameter of 0.000714 inch, a minimum of 0.000625 inch, and a mean of 0.000635 inch. *Fiji sea-island* is less regular in its properties than the two preceding varieties, and though its maximum length is somewhat greater than sea-island itself, yet the mean length is about the same, as is also the diameter. This cotton, however, has a very irregular staple and contains a large percentage of imperfect fibres, which causes the waste to be rather high. The number of twists in the fibre is also less and does not occur as regularly. *Gallini Egyptian* cotton is sea-island cotton grown in Egypt.‡ It is somewhat inferior to the American varieties in general properties.§ It possesses a yellowish color, which distinguishes it from the product of all other countries.‖ The maximum length of the fibre is $1\frac{5}{8}$

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* Sea-island cotton may be cultivated in any region adapted to the olive and near the sea, the principal requisite being a hot and humid atmosphere, but the results of acclimatization indicate that the humid atmosphere is not entirely necessary if irrigation be employed, as this species is undoubtedly grown extensively in Egypt. As a rule, the quality of the staple increases with the proximity to the sea; but there are exceptions to this rule, as that grown on Jamaica and some islands is of rather low grade, while the best fibre is produced along the shores of Georgia and Carolina. (*Bulletin No. 33*, U. S. Dept. Agric.)

† Sea-island cotton gives a smaller yield of lint than any variety of cotton grown in America, but, on account of the greater length and fineness of staple, it has a much higher market value.

‡ The *Bamia* variety of Egyptian cotton is a form of sea-island cotton to which Todaro has given the varietal name of *polycarpum*. It is characterized by numerous flowers springing from a single axil, and an erect, slightly branching habit, hence giving a large yield per acre. It was once thought that the *Bamia* cotton was a hybrid between okra and cotton, but in a Kew Report (1887, p. 26) this is shown to be incorrect.

§ Gallini cottons have the bad feature of containing considerable undeveloped and short fibre, and this somewhat lessens its commercial value. Peruvian sea-island also possesses this same defect, but, in addition, contains usually quite a large amount of foreign matter, such as broken leaf, sand, seed particles, etc.

‖ The fibre of Egyptian cotton is especially adapted to the manufacture of hosiery yarns and yarns for mercerizing. The United States imports Egyptian cotton to the value of about $10,000,000 per year.

inches, the minimum $1\frac{1}{4}$ inches, and the mean $1\frac{1}{2}$ inches. The fibres differ very little in their diameter, the average being 0.000675 inch. *Peruvian sea-island* is somewhat coarser in structure than the sea-island proper, being more hairy in appearance; it has a slight golden tint. In staple it varies from $1\frac{3}{8}$ inches in length to $1\frac{3}{4}$ inches, with a mean of $1\frac{1}{2}$ inches. *Tahiti sea-island* resembles the Fiji variety very closely; it has a creamy color. The length of staple varies from $1\frac{1}{4}$ to $1\frac{3}{4}$ inches, with a mean of $1\frac{1}{2}$ inches. It shows a considerable percentage of imperfect fibres due to a short undergrowth on the seed. Its average diameter is 0.000641 inch.

Gossypium herbaceum.*—*Smyrna* cotton is grown principally in Asiatic Turkey. It has a rather characteristic appearance under the microscope, being very even in its diameter but irregular in its twist, showing many fibres where the twist is almost entirely absent. In length the staple varies from $\frac{7}{8}$ to $1\frac{1}{8}$ inches, with a mean of 1 inch; the mean diameter is about 0.00077 inch. *Brown Egyptian* cotton is supposed to be indigenous to that country.† It is characterized by a fine golden color, and great

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* The cultivated cottons of to-day are far different from the original form of the *G. herbaceum*, which gave only 28 to 29 per cent. of fibre, with a staple 20 to 30 mm. long. The proportion of fibre has been greatly increased, reaching as high as 36 and even 40 per cent. in some varieties, while the length of staple has increased correspondingly, sometimes reaching fully three times its original length.

† The first variety of cotton to be cultivated in Egypt was called Makko-Jumel; this went through many changes and evolutions, and gradually changed its color to a yellowish brown, the new variety being known as Ashmouni, from the valley of Ashmoun, where the change was first noticed. The principal varieties of Egyptian cotton now grown are the Ashmouni, Mitafifi, Bamia, Abbasi, and Gallini. Formerly the Ashmouni formed the bulk of the Egyptian crop, but it is now almost entirely superseded by the Mitafifi. In color it is a light brown, and its staple is over an inch in length. The Mitafifi cotton is said to have been discovered by a Greek merchant in a village of that name; it is characterized by the seed having a bluish-green tuft at the extremity. Its color is a richer and darker brown than the Ashmouni; the fibre is long, strong, and fine, and very desirable in the market. The Bamia cotton is the next most extensively cultivated; the fibre is poor compared with the foregoing, being light brown in color and not very strong. The Abbasi cotton is of rather recent introduction; in its general properties it resembles Mitafifi, but has not the same strength. The Gallini cotton was derived from sea-island, but it has almost entirely disappeared

toughness and tensile strength. It is, however, shorter and coarser than the Gallini cotton. In length of staple it varies from $1\frac{1}{8}$ to $1\frac{1}{2}$ inches, with a mean of $1\frac{1}{4}$ inches; the mean diameter is 0.000738 inch. *African* cottons are all derived from the *herbaceum* species. These cottons have a slight brownish tint, and always contain a large amount of short fibres. The fibres also vary much in diameter and thickness of the tube-walls, and many exhibit a transparent appearance under the microscope. Yarns made from these cottons are always uneven on the surface. The length of staple varies from $\frac{7}{8}$ to $1\frac{1}{8}$ inches, with an average of 1 inch; the mean diameter is 0.00082 inch. *Hingunghat* cottons are Indian varieties; the quality of these varies with the soil and climate of the province in which they are grown. As a rule, they are of rather inferior grade; the best variety is the *Surat* cotton. Under the microscope the Hingunghat cotton shows much variation in diameter, although it possesses fewer twists than the better grades of cotton, yet, unlike the African varieties, it shows very few fibres without any convolutions at all. In length of staple it varies from $\frac{7}{8}$ to $1\frac{1}{8}$ inches, with a mean of 1 inch; the average diameter is 0.00084 inch. *Broach, Tinnevelly, Dharwar, Oomrawuttee, Dhollerah, Western Madras, Comptah, Bengal,* and *Scinde* are other varieties of Indian cotton, all belonging to the *herbaceum* species. They have the same general properties and staple as the preceding, becoming more and more inferior, however, in the order of the list given.

Gossypium hirsutum. — *White Egyptian,* unlike the brown variety described above, is not indigenous, but was transplanted from America. In length of staple it varies from $1\frac{1}{8}$ to $1\frac{3}{8}$ inches, with a mean of $1\frac{1}{4}$ inches; the diameter averages 0.00077 inch. This cotton shows a large number of fibres having but partially developed spiral twists. *Orleans* cotton is the typical American variety, and is perhaps the best of the American cottons.* The

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from cultivation, as its quality has greatly deteriorated. Egyptian cotton, as a class, is not so fine as sea-island, but is better than American upland cotton, that is, for goods requiring a smooth finish and a high lustre, the staple being strong and silky.

* In the United States only the herbaceous cottons are cultivated to any extent; the shrubby and arboreous are occasionally grown as curiosities, but they sel-

fibres are quite uniform in length, having an average staple of about 1 inch and a mean diameter of 0.00076 inch. It is almost pure white in color. *Texas* cotton much resembles the foregoing, but has a slight golden color; its length and diameter of staple are the same. *Upland* cotton * is another very similar variety; its length of staple, however, is somewhat less than the foregoing, averaging but $\frac{15}{16}$ inch. Its twist is rather inferior to the Orleans, and it shows a larger number of straight fibres. *Mobile* cotton is the most inferior of the American varieties; it varies in length of staple from $\frac{3}{4}$ to 1 inch, with a mean of $\frac{7}{8}$ inch; its average diameter is 0.00076 inch. It shows about the same microscopic appearance as upland cotton. *Santos* cotton comes from Brazil; it is not much in demand on account of its inferior quality.†

Gossypium peruvianum.—Rough Peruvian; this cotton has a light creamy color and is rather harsh and hairy in feel.‡ In length of staple it varies from $1\frac{1}{8}$ to $1\frac{7}{16}$ inches, with a mean of $1\frac{1}{4}$ inches; its mean diameter is about 0.00078 inch. Most of the fibres

dom or never produce any lint in regions having as low a mean temperature as the American cotton belt. (*Bulletin No. 33*, U. S. Dept. Agric.)

* There are more than a hundred recognized horticultural varieties of upland cotton in cultivation, all belonging to one botanical species *G. hirsutum*, native to the American tropics. The original wild plants in the tropical zone were perennials, but the plant is cultivated as an annual. (*Yearbook*, U. S. Dept. Agric., 1903.)

† The variety known as *G. braziliense* is a representative of the so-called "kidney cottons." In these cottons the seeds of each cell are closely adherent in an oval mass, whereas in the other varieties of cotton the seeds are free from each other. *G. braziliense* is an arborescent plant with very large 5 to 7 divaricate-lobed leaves and very deeply laciniate involucral bracts. The Brazilian cottons appearing in trade under the names Santos, Ceara, Pernambuco, etc., do not seem to belong to *G. braziliense*, as they are not kidney cottons; they evidently belong to the *G. barbadense* and *G. herbaceum* species.

‡ Peruvian cotton is often called *kidney cotton*, being characterized by the seeds in each lobe of the capsule clinging together in a compact cluster. These seeds are black and without a persistent fuzzy covering. The lint shows a wide variation in color and texture—white, brown, reddish, rough and harsh, or smooth and soft. Most of it has a shorter, coarser, and more wiry fibre than that of American upland. The lint of some varieties is much like wool in appearance It is imported chiefly for mixing with wool or for producing special effects. Kidney cotton is found in Central America and also in the Philippines and other tropical islands of the Pacific, but it is not cultivated in commercial quantities outside of South America. (*Yearbook*, U. S. Dept. Agric., 1903.)

are only partially twisted. *Smooth Peruvian* has a soft, smooth feel, but the staple is not so strong as the preceding. The length is about the same as the foregoing, as is also the diameter. *Pernambuco* has a slight golden color and feels harsh and wiry. It is a variety of Brazilian cotton. It is rather regular in length of staple, the mean being $1\frac{1}{4}$ inches. The diameter averages 0.00079 inch. Under the microscope the twists appear regular and well defined. *Maranhams* cotton is very similar to the preceding in microscopic appearance and length and diameter of staple. *Ceara* is a Brazilian cotton, rather inferior to the others by reason of its considerable variation in length of staple. *Maceo* is a similar variety, but somewhat harsher. *West Indian* cottons nearly all belong to the *peruvianum* species; they are usually long in staple and harsh and wiry in feel, and only of moderate strength. The length is quite uniform and averages $1\frac{1}{4}$ inches. The diameter varies considerably, but has an average of about 0.00077 inch. The twist is short and very uniform, surpassing even sea-island in this respect.

Chinese cotton, also known as *Nankin* cotton, is classified as *G. religiosum;* it yields a naturally colored fibre, being rather dark yellowish brown. It grows principally in China and Siam.

CHAPTER X.

THE PHYSICAL STRUCTURE AND PROPERTIES OF COTTON.

1. Physical Structure.—Physically the individual cotton fibre consists of a single long cell, with one end attached directly to the surface of the seed. While growing the fibre is round and cylindrical, having a central canal running through it; but, after the enclosing pod has burst, the cells collapse and form a flat ribbon-like fibre, which shows somewhat thickened edges under the microscope. The juices in the inner tube, on the ripening of the fibre, are drawn back into the plant, or dry up on exposure to light and air, and in so doing cause the fibre to become twisted into the form of an irregular spiral or screw-like band, by reason of the unequal collapse and contraction of the cell-wall.* Fibres that have not ripened differ somewhat in these characteristics, being straight and having the inner canal stopped-up, in consequence of which they do not spin well and are difficult to dye, showing up as white specks in the finished goods; this is known as *dead cotton*.† The presence of an inner canal in the cotton fibre no doubt adds to its absorptive power for liquids, and its capillary action allows cotton to retain salts, dyestuffs, etc., with considerable power; but too much importance in this respect must not be attributed to the canal, for when cotton is mercerized the canal is almost entirely obliterated by the walls being squeezed

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* The number of twists in the cotton fibre in the raw state is said to be from 300 to 500 per inch.

† The presence of "dead cotton" is very objectionable, as the fibre is weak and brittle, and consequently reduces the strength and durability of the yarn into which it may go. There is a considerable amount of unripe or partly ripened bolls always to be found in cotton-fields, and the fibres from these consist almost exclusively of "dead cotton." The proper utilization of such cotton is a serious question, for the fibre is too weak to be used for spinning, and the cost of gathering and ginning makes the fibre too expensive for most other purposes, such as for absorbent cotton, cotton batting, or material for guncotton.

together (see Fig. 54), and yet mercerized cotton is much more absorptive of dyes, etc., than ordinary cotton. The capillarity

FIG. 54.—Cross-sections of Mercerized Cotton Fibres, showing the Appearance of the Inner Canal.

of the cotton fibre is no doubt principally due to the existence of minute pores which run from the surface inward. The crystallization of salts in these pores and in the central canal may lead to the rupturing of the fibre, as, for instance, when filter-paper is made by disintegrating cotton fibres by saturating them with water and then freezing them.

The following table of the length and diameter of different

Name of Cotton.	Length in mm.	Diameter in μ.	Name of Cotton.	Length in mm.	Diameter in μ.
Sea-island.	41.9	9.65	*West Indian.*	32.3	19.6
Edisto.	46.6	. . . .	*American.*	. . . .	20.9
Wodomalam	39.0	. . . .	Orleans.	27.0	19.2
John Isle	39.3	. . . .	Upland	29.5	19.4
Florida.	45.7	16.18	Texas.	24.3	16.6
Fitschi.	48.7	16.7	Mobile.	25.0	19.4
Tahiti.	42.9	16.3	Georgia	25.4	10.3
Peruvian.	38.9	15.3	Mississippi.	24.2	3.4
Egyptian.	32.1	16.7	Louisiana.	25.0	. . . .
Gallini.	37.2	17.1	Tennessee.	25.1	15.0
Brown.	34.4	18.7	*African.*	27.6	20.8
White.	31.8	19.5	*Indian.*	. . . .	19.3
Smyrna.	28.5	22.8	Hingunghat	28.3	20.0
Brazilian	. . . .	18.8	Dhollerah.	28.2	21.5
Maranham.	28.8	20.4	Broach.	20.9	21.8
Pernambuco.	35.2	20.0	Tinnevelly.	23.0	21.0
Surinam.	30.2	. . . .	Dharwar.	23.6	21.0
Paraiba.	29.7	. . . .	Oomrawuttee. . .	24.1	21.5
Ceara.	28.1	20.0	Comptah	23.8	21.5
Maceo.	29.3	. . . .	Madras.	21.8	21.8
Peruvian rough	29.9	21.5	Scinde.	20.4	21.3
Smooth.	30.0	21.5	Bengal.	25.7	23.7
Agerian.	37.5	. . . .	*Chinese.*	21.4	24.1

varieties of cotton fibres has been collated as a mean of several observers.

The cotton fibre is rather even in its diameter for the greater part of its length, though it gradually tapers to a point at its out-growing end.   The different varieties of cotton show consider-able variation, both in length and diameter of fibre; in sea-island cotton the length is nearly 2 inches, while in Indian varieties it is often less than 1 inch.*   The diameter varies from 0.00046 to 0.001 inch; the longest fibres having the least diameter.

Evan Leigh (*Science of Modern Cotton Spinning*) gives the following summary of the length and diameter of cotton fibres:

Place of Growth.	Kind of Cotton.	Length in Inches.			Diameter in Inches.		
		Min.	Max.	Mean.	Min.	Max.	Mean.
United States..	New Orleans...	0.88	1.16	1.02	.000580	.000970	.000775
Sea-islands....	Long stapled..	1.41	1.80	1.61	.000460	000820	.000640
South America.	Brazilian......	1.03	1.31	1.17	.000620	.000960	.000790
Egypt.........	Egyptian......	1.30	1.52	1.41	.000590	.000720	.000655
India....... {	Native........	0.77	1.02	0.89	.000649	.000040	.000844
	American seed.	0.95	1.21	1.08	.000654	.000996	.000825
	Sea-island seed.	1.36	1.65	1.50	.000596	.000864	.000730

* *Bulletin No. 33* (U. S. Dept. Agric.) gives the following table compiled from numerous measurements taken during a period of years, showing the maxi-mum, minimum, and average length of fibre for some of the most important varieties of cotton, as well as the average diameter of the same:

Variety.	Length in Inches.			Diameter, Inches.
	Max.	Min.	Aver.	
Sea-island...............	1.80	1.41	1.61	.000640
New Orleans.............	1.16	0.88	1.02	.000775
Texas..................	1.12	0.87	1.00	.000763
Upland.................	1.06	0.81	0.93	.000763
Egyptian...............	1.52	1.30	1.41	.000655
Brazilian...	1.31	1.03	1.17	.000790
Indian varieties:				
Native..............	1.02	0.97	0.89	.000844
American seed........	1.21	0.95	1.08	.000825
Sea-island seed........	1.65	1.36	1.50	.000730

From these measurements it will be observed that, as a rule, the longer the fibre the less is its diameter.   The extreme variations in the above measurements of length is from 0.25 to 0.30 inch.   In proportion to the size of the fibre, the variation in diameter is much greater than that for the length.

Hannan gives the following varieties and qualities of cotton to be met with in commerce.

Types.	Variety.	L'gth, Ins.	Diameter, Ins.	Counts.	Use.	Properties.
Sea-island..	Edisto......	2.20	.00063	300–400	Warp or weft	Long, fine silky, and of uniform diameter
	Florida.....	1.85	.00063	150–300	do.	Shorter, but similar to above
	Fiji........	1.75	.00063	100–250	do.	Less uniform in length, but silky and cohesive
	Tahiti......	1.80	.00063	"	do.	Good, fine, and glossy staple
Egyptian...	Brown.....	1.50	.0007c	120–down	do.	Long, strong, highly endochromatic
	Gallini.....	1.60	.00066	250–down	Warp	High-class staple of good strength
	Menouffieh..	1.50	"	200–down	Weft	Of good staple and lustre
	Mitafifi....	1.25	"	100	Warp or weft	Fairly good staple
	White......	1.00	.00078	70	do.	Pearly white, good long staple
Peruvian...	Rough......	1.25	.00078	50–70	Warp	Strong, woolly, and harsh staple
	Smooth.....	1.00	"	"	Weft	Less woolly, and softer staple
	Red........	1.25	"	40–50	Warp	Color weaker and harsher than brown Egyptian
Brazilian...	Pernambuco.	1.50	.00079	50–70	Warp	Strong and wiry
	Maranham..	1.15	"	50–60	do.	Harsh and wiry
	Ceara......	1.15	"	60	Weft	Good, white, and cohesive staple
	Paraiba.....	1.20	"	50–60	Warp or weft	Fairly strong, harsh, of good color
	Rio Grande.	1.15	"	40–50	Weft	Soft, white, and harsh staple
	Maceio.....	1.20	.00084	40–60	Warp or weft	Soft, pliable, and good for hosiery
	Santos......	1.30	"	50–60	Weft	Exotic from American seed, white and silky staple
	Bahia......	.....	......	40–50	Warp or weft	Fairly strong, but harsh and wiry
American...	Orleans....	1.1	.00077	34–46	do.	Medium length, pearly, white
	Texas......	1.05	"	32–40	do.	Similar to above, rather harsher and more glossy
	Allanseed...	1.20	"	50–60	Warp	Good, white, long; blends with brown Egyptian
	Mobile.....	1.00	.00076	40–50	Warp or weft	Even-running staple, soft and cohesive

Types.	Variety.	L'gth, Ins.	Diameter, Ins.	Counts.	Use.	Properties.
American...	Norfolks....	1.00	00076	40–50	Weft	Used for Oldham counts of 50's
	St. Louis....	0.90	"	30–32	Warp	S t a p l e irregular, glossy, but short
	Ronoaks....	0.90	"	30–34	do.	A white and strong staple
	Boweds....	.....	......	36	Weft	Similar to uplands
	Benders....	1.10	.00077	60	Warp	Strong, creamy or white, for Turkey-red dyes
	Memphis...	1.00	"	40–50	do.	Bluish white, for extra hard twists
	Peelers.....	1.25	"	60–80	Weft	Long, silky, fine staple; adapted for velvets, etc.
	Uplands....	1.00	"	36–40	do.	Glossy when clean, apt to be dull, sandy, and leafy
	Alabama....	0.90	"	26–30	Warp or weft	Short staple, of less strength, varying color
	Linters.....	.....	......	8–10	Weft	Short - stapled gin waste
	Tennessee..	0.90	"	28	Warp or weft	Of varying length and color
Greek......	Smyrna.....	1.25	......	36–40	Warp	Harsh and strong, adapted for double yarns
African....	Lagos......	0.80	......	20–26	Weft	Dull and oil-stained, irregular in length and strength
West Indian	Carthagena.	1.50	......	26	Warp	From exotic seeds; fairly strong
	La Guayran.	1.20	......	40	Warp or weft	Irregular and short, but silky staple
China......	China......	1.00	......	30	Weft	Harsh, short, and white
Australian..	Queensland.	17.5	.00066	120–200	Warp or weft	Long, white, silky, fine diameter
East Indian	Oomrawuttee	1.00	.00083	26–32	Warp	Short, strong, and white
	Hingunghat.	1.00	"	28–36	Weft	Best white Indian staple
	Comptah...	1.05	......	....	Warp or weft	Generally dull and charged with leaf
	Broach.....	0.90	......	28–36	Weft	Like Hingunghat, gives good white weft
	Dharwar...	1.00	......	28	Warp	Exotic from American seeds
	Assam......	0.50	......	15–20	Warp	White, but harsh, to blend with other cottons

Types.	Variety.	L'gth, Ins.	Diameter, Ins.	Counts.	Use.	Properties.
East Indian	Bengals.....	0.80	......	20–30	Warp or weft	Dull and generally charged with leaf
	Bilatu......	0.50	......	10–20	do.	Weak, brittle, and coarse
	Dhollerah...	0.70	......	15–20	do.	Strong, dull, and co-hesive
	Surat.......	0.60	......	10–15	do.	Dull and leafy, often stained
	Scinde......	0.50	......	to 10	do.	Very strong, dull, short, and poor staple
	Tinnevelly..	0.80	......	24–30	do.	Lustrous white, soft, and adapted for hosiery
	Bhownuggar	1.00	......	28–30	Warp	White when clean; often leafy and dirty
	Cocoanada.	0.70	......	10–14	Brown weft	Brown and dull; used as quasi-Egyptian
	Bourbon....	1.00	......	30	Weft	Exotic; of good staple; scarce
	Khandeish..	0.80	.00083	20–26	Warp or weft	Similar in class to Bengal
	Madras or Westerns..	0.70	......	15–20	do.	Used for low yarns in coarse towelling, etc.
	Rangoon....	0.60	......	to 10	Warp or weft	Weak, dull, often stained and leafy
	Kurrachee..	0.90	......	28	do.	Fairly strong, dull, and leafy
Italian.	Calabria....	0.90	......	26–28	do.	Fairly strong, irregular and dull, leafy
Turkey.	Levant.....	1.25	.00077	36–40	Warp	Harsh, strong, and white

Monie (*The Cotton Fibre*) gives the following tables descriptive of the principal commercial varieties of cotton.* As the descriptions given in these tables vary, in some respects, quite considerably from the preceding tables of Hannan, it is probably best that both should be given:

* Monie remarks in connection with this table that it will be observed that the Fiji and Tahiti sea-island cottons are the most irregular in the length of their fibres, the extreme variation in both being half an inch. As long and short cotton never incorporate well together nor adapt themselves to the production of a regular yarn in appearance and strength, it is easy to understand that they are relatively wasteful cottons to work. In any spinning mill where they are used, it will be found that the quantity of "fly," "combings," and "flat waste" made at the various machines is very great, and the reason of this is that in any cotton where the fibres are of different lengths, the long and strong will have a tendency to throw out the short and weak. The cotton which presents the greatest regularity is the Orleans. In comparing the diameters of various cottons with their lengths, it will be found that the longest cottons are usually the finest.

Commercial Name.	Length of Fibres.			Extreme Variation, Inches.	Mean Diameter of Fibre, Inches.	Counts of Yarn.	Class: T = Twist. W = Weft.	Characteristics.
	Max. Inches.	Min. Inches.	Mean Inches.					
Sea-island . .	2	1.75	1.87	0.25	0.000135	180–300	T. & W.	Length and small diameter; silkiness; free from impurities; contains some short and undeveloped fibre
Florida	1.81	1.50	1.65	0.31	0.000637	150–200	do.	do.　do.　do.
Fiji Sea-island	2.12	1.67	1.87	0.50	0.000637	150–200	do.	Similar to preceding, but weaker and containing larger percentage of unripe fibre
Gallini	1.67	1.25	1.43	0.37	0.000675	70–150	do.	Of a light golden color, very strong and much easier to work into yarn than sea-island
Peruvian Sea-island . . .	1.75	1.37	1.56	0.37	0.000675	80–140	do.	Not so fine or silky as sea-island proper; of a light golden tint; fibre moderately strong; apt to contain much dirt
Tahiti Sea-island	1.75	1.25	1.50	0.50	0.000641	100–130	W.	Similar to Fiji in color and appearance, but rather weak, and contains more "neppy" fibre
Brown Egyptian	1.50	1.12	1.31	0.37	0.000738	50–90	T. & W.	Of a golden color; strong, clean, and easy to work
Rough Peruvian	1.44	1.12	1.28	0.31	0.000781	40–70	T.	Of a light cream color; feels harsh and wiry; very clean; moderately strong
Smooth Peruvian	1.44	1.12	1.28	0.31	0.000769	40–70	W.	Soft, smooth, and pliable; resembles Orleans in color, and in other respects the "rough" variety

						T. & W.	
White Egyptian	1.37	1.12	1.25	0.25	0.000769	40–70	T. & W.	Contains considerable broken leaf; color light golden; fibres fairly strong
Pernambuco	1.37	1.12	1.25	0.25	0.000787	40–60	T.	Finest of Brazilian crop; similar in color to above; harsher and wirier in staple
Maranham	1.19	0.94	1.06	0.25	0.000787	30–52	T. & W.	Of a dull golden tint; fibres not so strong as Pernambuco; sometimes quite dirty
Ceara	1.19	0.87	1.03	0.32	0.000787	30–50	do.	Fairly clean; color dull white; medium strength
Orleans	1.12	0.94	1.03	0.19	0.000757	30–50	do.	Finest of American white cottons; generally clean; economical to work; fibres soft and moist and of fair strength
Texas	1.12	0.87	1.00	0.25	0.000763	30–50	do.	Of a light golden tint; other characteristics similar to Orleans
Upland	1.06	0.81	0.94	0.25	0.000763	to 42	W.	Similar to Orleans, but somewhat weaker
Mobile	1.00	0.75	0.87	0.25	0.000763	to 36	do.	Never so clean as either Upland or Orleans, and not quite so strong
Smyrna	1.12	0.87	1.00	0.25	0.000769	to 42	do.	Color a dull white; fairly clean; of medium strength
West Indian	1.37	1.06	1.22	0.31	0.000769	to 40	T. & W.	Contains more or less impurities; moderate in strength; fibres rather harsh and dry
African	1.19	0.87	1.03	0.31	0.000819	to 36	T.	Of a clear light golden tint. All crops contain some very short fibres, but fairly free from other impurities; moderately strong
Hingunghat	1.19	0.87	1.03	0.31	0.000833	to 36	T.	Of a light golden tint; fibres strong, often rather dirty; the fines varieties of Indian cottons

Commercial Name.	Length of Fibres.			Extreme Variation, Inches.	Mean Diameter of Fibre Inches.	Counts of Yarn.	Class: T = Twist W = Weft.	Characteristics.
	Max. Inches.	Min. Inches.	Mean Inches.					
Broach............	1.00	0.69	0.84	0.31	0.000833	to 28	T. & W.	Of a high golden tint; fairly clean; moderately strong
Tinnevelly.........	1.06	0.69	0.87	0.37	0.000826	26 down	T.	Fairly strong; of a dull creamy color; very elastic; moderately clean
Dharwar...........	0.93	0.69	0.87	0.25	0.000826	to 20	T. & W.	Fairly clean; much broken fibre; other characteristics similar to Broach
Oomrawuttee.......	1.06	0.75	0.90	0.31	0.000847	to 20	do.	Always rather dirty; of a creamy color and strong; fibre regular
Dhollerah..........	1.06	0.84	0.93	0.25	0.000847	to 20	W.	Very dirty; of a whitish color; fibres rather weak
Madras (Western)....	1.00	0.75	0.87	0.25	0.000833	to 20	T.	Exceedingly dirty and wasteful to work; of a deeper tint than Oomrawuttee, and fairly strong
Comptah...........	1.00	0.75	0.87	0.25	0.000847	to 15	W.	Contains much leaf, etc., broken into fine particles; of a brown tint, and fibres rather weak
Bengal............	1.00	0.75	0.87	0.25	0.000869	to 15	T.	Very dirty; fibres harsh but strong; of a golden tint
Scinde............	0.87	0.50	0.65	0.37	0.00084	to 12	T. & W.	The poorest of commercial cottons; fairly clean; of a dull white color

Höhnel gives the following table for the thickness of different varieties of cotton:

	mm. / 1000
North American:	
Sea-island..................................	14
Louisiana and Alabama...................	17
Florida....................................	18
Upland and Tennessee....................	19
Southern and Central American..............	15–21
Average.......................	19
East Indian:	
Dollerah and Bengal......................	20
Madras....................................	28
Chinese:	
Nankin....................................	25–40
Egyptian:	
Makko.....................................	15
Levianthan................................	24
European:	
Spanish...................................	17
Italian....................................	19

According to Wiesner, the thickest part of the cotton fibre is not directly at the base, but more or less towards the middle. He gives the following measurements of thickness at different parts of the fibre:

Position.	*G. arboreum,* 25 mm. long. mm. / 1000	*G. acuminatum,* 28 mm. long. mm. / 1000	*G. herbaceum,* 25 mm. long. mm. / 1000
Point	0	0	0
1	8.4	4.2	4.2
2	21	21.6	5.8
3	29	16.8	10.0
4	25	29.4	16.8
5	29	17.0	21.0
6	25	21.1	16.9
7	21	21.1	21.0
Base	17	21.0	16.8
Mean	19.5	16.9	12.5

The length of the cotton fibres attached to a single seed is by no means constant. The longest fibres usually appear at the crown of the seed, while the shortest occur at the base. There is also frequently an undergrowth of very short fuzzy fibres. In

ginning the very short fibres are ordinarily not removed from the seed, but more or less always appear with the ginned cotton. These short fibres are termed "neps," and their presence in any considerable amount materially affects the commercial value of the cotton. This short undergrowth of neps appears to be made up of incompletely developed or immature fibres, though neps may also arise through excessive breaking of fibres by imperfect manipulation in the carding and spinning processes.

Bowman (*Structure of the Cotton Fibre*) gives the following table showing the extreme variation in the length and diameter of different kinds of cotton:

Cotton.	Variation in Length.	Variation in Diameter.
American (Orleans).........	0.28 in.	0.000390 in.
Sea-island............	0.39 "	0.000360 "
Brazilian.	0.28 "	0.000340 "
Egyptian........................	0.22 "	0.000130 "
Indian (Surat)..	0.25 "	0.000391 "

According to the measurements of Wiesner, the average width (diameter of the broadside) of the various kinds of cotton are as follows:

Gossypium herbaceum......... ... . 18.9 μ
      "   *barbadense*.................................. 25.2 "
      "   *conglomeratum*............ .... 25.5 "
      "   *acuminatum*. .... 29.4 "
      "   *arboreum*.................................... 29.9 "
      "   *religiosum*............ .. .. 33.3 "
      "   *flavidum*. .... 37.8 "

Bowman calls attention to the fact that Egyptian cotton is the most regular in both length and diameter; while sea-island cotton, though possessing the greatest length and fineness of staple, also exhibits the greatest variation. It is also noticeable that the variation in the diameter is proportionately very much larger than the variation in the length. Bowman also gives an interesting comparison of the size of the individual cotton fibre with objects of common experience. If a single fibre of American cot-

ton were magnified until it becomes 1 inch in diameter, it would be a little over 100 feet long, while a sea-island fibre of the same diameter would be about 130 feet. It requires from 14,000 to

FIG. 55.—Showing Comparative Lengths of Different Cottons. (Maxima and Minima.) (After Lecomte.)
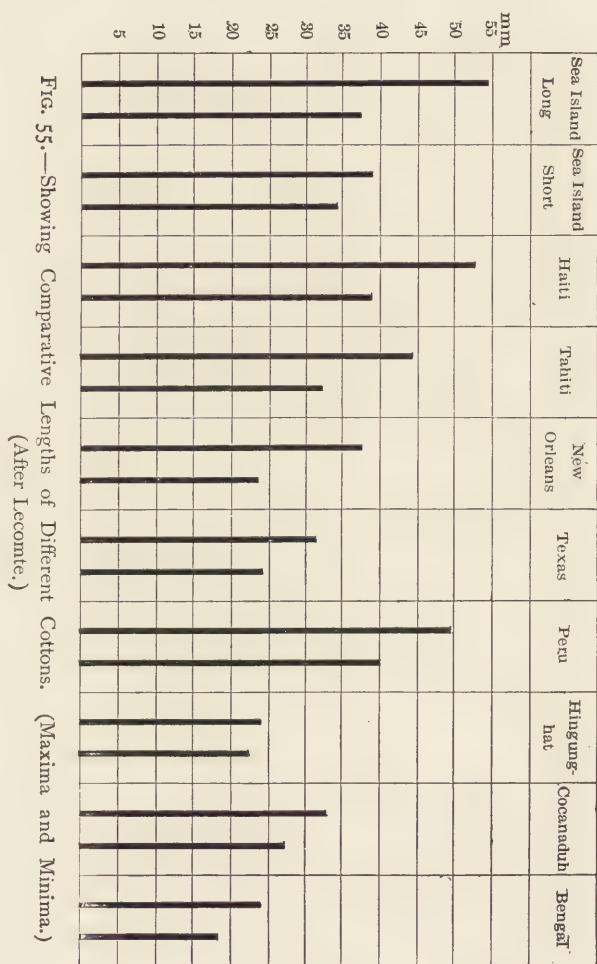
20,000 individual fibres of American cotton to weigh 1 grain, hence there are about 140,000,000 in each pound, and each fibre weighs on an average only about 0.00006 grain. If the separate fibres contained in one pound were placed end to end in a straight line, they would reach 2,200 miles.

Höhnel gives the following table of the different varieties of cotton arranged according to their length of staple:

Gossypium barbadense		(Sea-island)................	4.05 cm.
"	"	(Brazilian)................	4.00 "
"	"	(Egyptian)................	3.89 "
"	vitifolium	(Pernambuco)............	3.59 "
"	conglomeratum	(Martinique).............	3.51 "
"	acuminatum	(Indian)	2.84 "
"	arboreum	(Indian).................	2.50 "
"	herbaceum...	(Macedonian).............	1.82 "
"	"	(Bengal).................	1.03 "

From its behavior with a solution of ammoniacal copper oxide, the cotton fibre appears to consist of four distinct parts structurally. When treated with this solution and examined under the microscope, the fibre is seen to swell, but not uniformly; it seems that at regular intervals there are annular sections which do not swell.* The result is that the fibre assumes the form of a distended tube tied at intervals somewhat after the manner of a string of sausages. Soon the main portion of the fibre begins to dissolve, whereupon the walls of the central canal are seen quite prominently; the dissolving action proceeds rapidly, but apparently there is a thin cuticular tissue surrounding the fibre which resists the action of the solvent for a much longer time than the inner portion. The walls of the central canal also resist the action of the liquid to even a greater extent than the external tissue; the annular contracted ligatures in the fibre also persist after the rest of the fibre has dissolved. Thus we have four structural parts made evident (see Fig. 60):

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* Höhnel considers these ligatures as merely parts of the cuticle; he explains their formation by the fibre swelling so considerably as to rupture the undisturbed cuticle, which in places adheres to the fibre in the form of irregular shreds which are visible only with difficulty. In other places where the rupture occurs obliquely to the length of the fibre, the cuticle becomes drawn together in annular bands surrounding the fibre, while between these rings the much-distended cellulose protrudes in the form of globules. The inner membrane or canal which persists after the rest of the fibre has dissolved is an exceedingly thin tissue of dried protoplasm which was contained in the living fibre. On bleached cotton the cuticle may be almost entirely lacking, and hence such fibres will not exhibit the characteristic appearance above mentioned.

(*a*) The main cell-wall, probably composed of pure cellulose, and rapidly and completely soluble in the reagent.

(*b*) An external cuticular fibre, probably of modified cellulose, and more resistant to the action of the reagent.

(*c*) The wall of the central canal, which resists the solvent power of the reagent even more than the cuticle.

(*d*) The annular ligatures surrounding the fibre at intervals, which persist even after the canal-walls have dissolved.

O'Neill (in 1863) first pointed out this complex structure of the cotton fibre. He says: "I believe that in cotton-hairs I could discern four different parts. First, the outside membrane, which did not dissolve in the copper solution. Second, the real cellulose beneath, which dissolved, first swelling out enormously and dilating the outside membrane. Thirdly, spiral fibres, apparently situated in or close to the outside membrane, not readily soluble in the copper liquid. These were not so elastic as the outside membrane and acted as strictures upon it, producing bead-like swellings of a most interesting appearance; and fourthly, an insoluble matter, occupying the core of the cotton-hair, and which resembled very much the shrivelled integument in the interior of quills prepared for making pens." He also notes that the insoluble outside membrane was not evident on bleached cotton, hence concluding that either it had been dissolved away, or some protecting resinous varnish had been removed, and then it became soluble. He also obtained the same general results by treatment with sulphuric acid and chloride of zinc in place of the ammoniacal copper oxide solution.

According to Butterworth, who observed the cotton fibre treated with the ammoniacal copper oxide solution under a magnification of 1,600 diameters, there are spiral threads apparently crossing and tightly bound round the fibre at irregular distances, also spiral threads passing from one stricture to another; the core of the fibre has a spiral form, and in cross-section shows the presence of concentric rings (see Figs. 58 and 59).

There appears to be some difference in the action of ammoniacal copper oxide solution on fibres of different physiological structure. Immature or unripe fibres dissolve readily without exhibiting

any structural differences. The tubular-shaped fibres swell out as a whole and finally dissolve without showing any structural modifications, except that in many cases an inner core is left.

Examination with the highest microscopic powers has not shown any cellular structure pertaining to the cellulosic contents of the cotton fibre; it is probably composed of fine layers superimposed one upon the other.

2. **Microscopical Properties.**—The microscopical characteristics of the cotton fibre are so pronounced as to readily differentiate it from all others. As already noted, it presents the appearance of a flat, ribbon-like band more or less twisted on its longitudinal axis (see Fig. 56). The edges of the fibre are somewhat thickened, and usually present irregular corrugations. The fibre also at times presents the appearance of a rather smooth flat band with little or no thickened edges. The twist * of the fibre does not appear to be continuous in one direction; a portion of a fibre may be twisted axially to the right, then exhibit a flattened portion without any twist at all, then again show an axial twist to the left. For about three-fourths of its length the fibre maintains a comparatively uniform diameter, then it gradually tapers to a point, where it is perfectly cylindrical and often solid (see Fig. 61). In some cases portions of a fibre may exhibit cylindrical and apparently solid spaces, doubtless caused by irregularities in the growth of the cell. At these places the strength of the fibre is weakened, and will not absorb solutions to the same degree as the rest of the fibre. The cell-wall is rather thin and the lumen occupies about two-thirds of the entire breadth and shows up very prominently in polarized light. Between its thickened edges the fibre exhibits the appearance of a finely granulated surface. Fibres of dead cotton, or those which have not reached their full maturity,

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* The twist of the cotton fibre appears to be a character acquired through cultivation, as it is not possessed by wild cotton. Monie (*The Cotton Fibre*, p. 25) explains the twist in cotton as follows: The rotary motion begins with the process of vacuation in the fibre, caused by the withdrawal of some of the fluid in the fibre when the seed begins to ripen, and as this is affected slowly and progressively, beginning at the extremity farthest from the seed and gradually receding towards the base, the free end or point becomes twisted on its own axis several times, thus producing the convoluted form exhibited under the microscope.
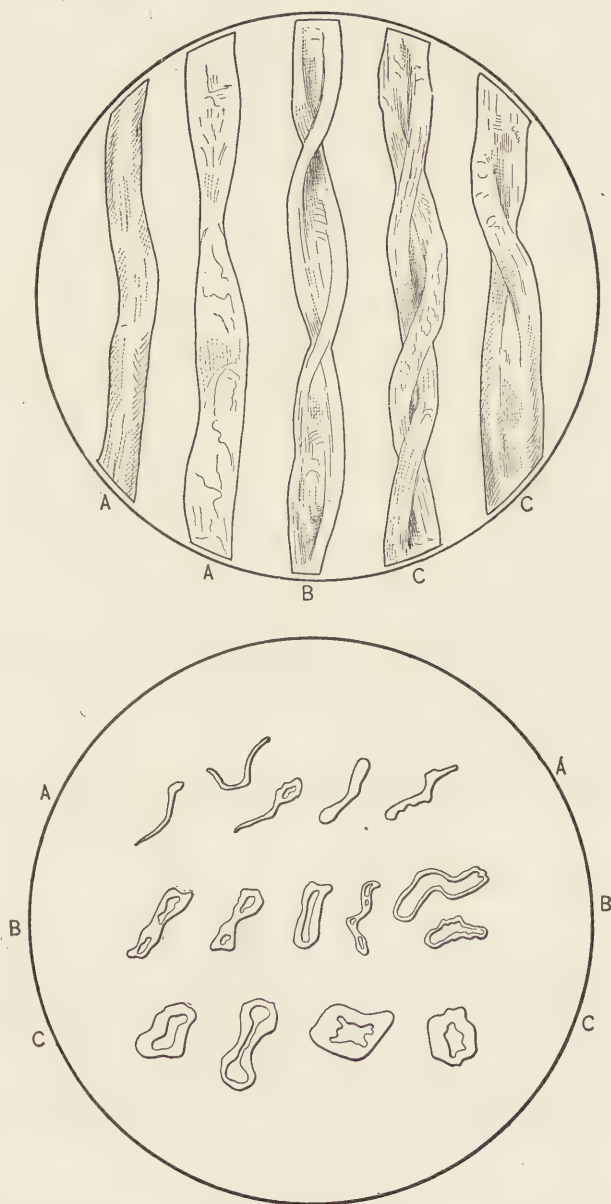
FIG. 56.—Cotton Fibres. ($\times$ 500.) Showing Longitudinal Veins and Cross-sections
A, A, unripe fibres; *B, B*, half-ripe fibres; *C, C*, fully ripe fibres.
(After *Bulletin No. 33*, U. S. Dept. Agric.)

are seldom twisted spirally and do not have a lumen, but are thin, transparent bands * (see Fig. 56, *A*).

Microscopically cotton fibres differ considerably among themselves, but in general may be divided into four classes:

(*a*) Fibres exhibiting a smooth, straight, flat appearance with no suggestion of internal structure. These include immature cotton fibres and also fibres which have overripened. The external wall of the fibre is very thin (see Fig. 56, *B*).

(*b*) Fibres exhibiting a normal appearance through some portions of their length, and in other parts a structureless appearance as in (*a*). These may be termed "kempy" fibres; the solid, tubular portion of the fibre is particularly resistant to the absorption of liquids and dyestuffs, and consequently remains uncolored while the rest of the fibre is dyed.

(*c*) Straight, tubular fibres exhibiting a well-defined internal structure and a transparent cell-wall of varying thickness.†

(*d*) Normal structure of twisted, band-like form (see Fig. 56, *C*).

In cross-section the immature fibres show only a single line with no structure, and but little or no indication of an internal opening. The mature fibre is thicker in cross-section and exhibits a central opening.

The most characteristic of the microchemical reactions for cotton is that with ammoniacal copper solution, already described. With bleached cotton the external cuticle may be absent, and hence such a fibre may not show any distension. With iodin and sulphuric acid the cotton fibre becomes blue in color, though the cuticle remains colorless. Tincture of madder gives an orange color; fuchsin produces a red color which is destroyed by the addition of ammonia. Flax does not show this latter reaction, hence this serves as a chemical means of distinguishing between cotton and linen.‡ Anhydrous stannic

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* Unripe cotton has not much value for purposes of manufacture, as it contracts and curls up in the warm atmosphere of the mill, and consequently yarn containing much unripe fibre depreciates considerably.

† Fibres of this character may often be mistaken under the microscope for linen, especially if the cell-wall is thick. The fibres of *Gossypium conglomeratum* are especially liable to show this form.

‡ Provided the linen is unbleached. Bleached linen shows scarcely any differences from cotton in its chemical tests.

chloride gives a black color, and sulphuric acid dissolves the cotton fibre rapidly.

3. Physical Properties.—The natural, spiral-like twist present in the cotton fibre causes the latter to be especially adaptable to

FIG. 57.—Root of Cotton Fibre. (×300.) Showing the Irregular Fracture caused by the Fibre being Torn from the Seed. (Micrograph by author.)

purposes of spinning. The spinning qualities of the cotton fibre, however, depend not only on the nature and amount of twist which causes the individual fibres to lock themselves firmly
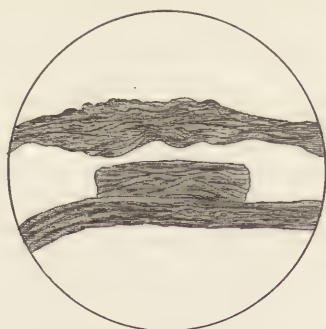
FIG. 58.—Cotton Swollen with Schweitzer's Reagent. (×300.) (Micrograph by author.)

together, but also on the length and fineness of staple. These three qualities in general will determine the character and fineness of yarn which may be spun from any sample of cotton. Sea-island cotton lends itself to the spinning of very fine yarns, being

spun to even 300's (that is, 300 hanks of 840 yds. each would weigh 1 pound), and in an experimental manner this cotton is said to have been spun as fine as 2000's.

In its **tensile strength** cotton stands between silk and wool; whereas, in **elasticity**, it is considerably below either of the other two fibres. The breaking strain of cotton will vary from 2.5
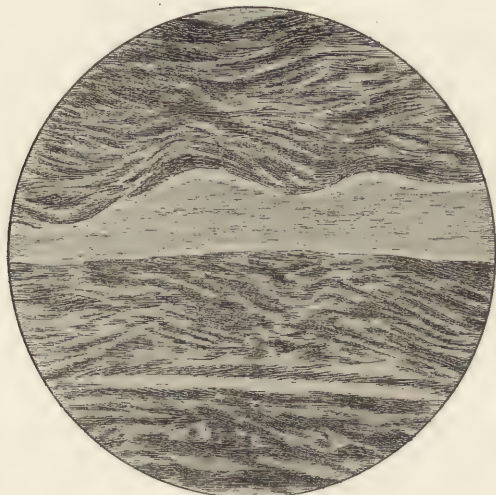
FIG. 59.—Portion of Fig. 58 More Highly Magnified. (×1500.) The Structure of the Cotton Cellulose is here plainly visible. (Micrograph by author.)

to 10 grams, depending on the fineness of staple; the finer the fibre the less will be its breaking strain.

The table at the top of page 205 shows the results of experiments on the tensile strength of different varieties of cotton.*

* Lecomte gives the following table showing the breaking strain of various cotton fibres:

Cotton.	Breaking Strain, Grams.
New Orleans.	9
Texas.	6.6
Peru (harsh).	10.5
Peru (long, silky).	4.1
Sea-island.	8
Port-au-Prince.	9.5
Haiti	5.1
Tahiti.	4.9
Jumel (brown).	7.6
Bengal.	4
Tinnevelly.	3.2

Cotton.	Mean Breaking Strain.	
	Grains.	Grams.
Sea-island (Edisto).............	83.9	5.45
Queensland.....................	147.6	9.59
Egyptian......................	127.2	7.26
Maranham.....................	107.1	6.96
Bengal.........................	100.6	6.53
Pernambuco.	140.2	9.11
New Orleans..................	147.7	9.61
Upland.......................	104.5	6.79
Surat (Dhollerah)..............	141.9	9.22
Surat (Comptah).	163.7	10.64

The full tensile strength of the individual fibre, however, is not utilized in the spun yarn.* Single yarns will give only about 20 per cent., or one-fifth of the breaking strain calculated from the strength of the separate fibres; two-ply yarns give about 25 per cent.†

The following table exhibits the comparative values of the tensile strength of different fibres. The "breaking length"

* Herzfeld (*Yarns and Textile Fabrics*, p. 95) gives the following tables showing the strength in grams of single cotton yarns of different counts, the numbering of the yarns being according to the metric system:

No.	Weak.	Medium.	Strong.	Very Strong.	No.	Weak.	Medium.	Strong.	Very Strong.
4	880	1000	1250	......	32	125	170	200	250
6	670	920	1080	1340	34	120	160	190	220
8	500	690	810	1000	36	110	150	180	210
10	400	550	650	800	38	105	140	170	200
12	330	460	540	660	40	100	135	160	190
14	285	390	460	570	50	......	110	130	140
16	250	340	400	500	60	......	90	110	125
18	220	300	360	440	70	......	80	90	105
20	200	280	320	400	80	......	70	80	95
22	180	250	295	360	90	......	60	70	85
24	170	230	270	330	100	......	55	65	80
26	150	210	250	310	110	......	50	60	70
28	140	200	230	290	120	......	45	55	60
30	130	180	215	260					

† Monie (*The Cotton Fibre*) gives a table (see page 206) showing the strength of cotton fibres after manufacture into yarn in relation to those in their natural condition.

refers to a length of thread which will break by reason of its own weight.

Fibre.	Breaking Length in Kilometres.	Tensile Strength, Kilograms per Square mm.
Cotton.............	25.0	37.6
Wool..............	8.3	10.9
Raw silk...........	33.0	44.8
Flax fibres.........	24.0	35.2
Jute..............	20.0	28.7
China grass........	20.0	
Hemp	30.0	45.0
Manila hemp.......	31.8	
Cocoanut fibre......	17.8	29.2
Vegetable silk.......	24.5	

4. Hygroscopic Quality.—Cotton is less hygroscopic than either wool or silk; under normal conditions it will contain from 5 to 8 per cent. of hygroscopic moisture, though in a very moist atmosphere this may be considerably increased.

The hygroscopic quality of cotton (and, in fact, any other vegetable fibre as well) has much to do with its proper condition during

CARDED COTTON.

Description of Yarn.	Average Number of Fibres in Cross-section of Yarn.	Test Strength of each Fibre in Grains.	Calculated Strength of Yarn in Lbs.	Actual Strength of Yarn in Lbs.	Percentage of Strength Utilized.
32's twist American cotton......	120	140	200	49.5	24.7
36's " " "	110	140	176	40.0	22.7
40's " " "	100	140	160	36.0	22.5
46's " Egyptian cotton........	132	146	220	52.0	23.6
50's " " "	110	146	184	46.0	25.0
60's " " "	100	146	167	33.5	20.6
70's ' brown Egyptian cotton ..	74	150	127	27.5	21.6
80's " " " "	60	150	103	23.5	22.8

COMBED COTTON.

Description of Yarn.	Average Number of Fibres in Cross-section of Yarn.	Test Strength of each Fibre in Grains.	Calculated Strength of Yarn in Lbs.	Actual Strength of Yarn in Lbs.	Percentage of Strength Utilized.
80's twist, Gallini cotton.........	90	120	100	25	20.3
120's " " "	55	120	66	18	24.2
120's " " "	50	120	68	15	22
143's " " "	40	120	55	13	23.6
165's " Sea-island cotton.......	45	100	55	13	25.4
190's " " "	38	100	43	10.5	24.4

the various processes of spinning and finishing. It also has an influence on the commercial valuation of the raw material, as the amount of hygroscopic moisture varies with atmospheric conditions, and it is important to have a normal standard of reference (see Conditioning of Wool, chapter iii).* Its influence on spinning

FIG. 60.—Appearance of Cotton Fibre on Treatment with Schweitzer's Reagent. (After Witt.)

a, transverse ligatures of disrupted cuticle; *b*, irregular shreds of cuticle torn apart; *c*, swollen mass of cellulose; *d*, walls of internal canal.

is even greater, and proper conditions of atmospheric moisture must be maintained in the spinning-room in order to achieve the best results; the spinning properties of raw cotton, however, are also affected by other substances associated with the cellulose of the fibre, but it is without question that the physical condition of cotton is largely influenced by its content of hygroscopic moisture, and this should be delicately adjusted by the spinner to meet the conditions of his work. The mechanical treatment

* The amount of "regain" allowed in the conditioning of cotton on the continent of Europe is $8\frac{1}{2}$ per cent.

of woven textile materials in finishing processes, such as mangling, beetling, calendering, etc., is also dependent for good results to quite an extent on the hygroscopic condition of the fibre; the amount of moisture present during the finishing operations, together with the method and degree of drying, should be carefully studied.*
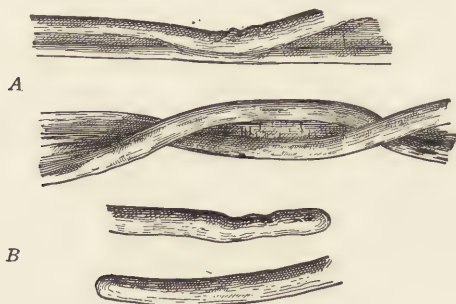
FIG. 61.—Cotton Fibre.   A, middle portions of fibre; B, points or ends of fibre.

When cotton is purified from its adhering waxy and fatty matters, it becomes remarkably *absorbent*. This quality is explained on the supposition that the ripe cotton fibre is made up of a series of tissues of cellulose, separated from each other by intercellular matter, in this way forming a series of capillary surfaces which are capable of exerting considerable capillary force upon any liquid in which the fibre may be immersed. Dry cotton also appears to be remarkably absorptive of gases; it is said that the fibre can absorb 115 times its volume of ammonia at the ordinary atmospheric pressure.

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* In testing the influence of moisture on the strength of cotton material, the Industrial Society at Mulhouse reports as follows:

Normal strength of cloth. 100
Saturated with moisture. 104
Dried on hot cylinder. 86
Again dampened. 103

It would appear from these results that the alternate moistening and hot drying of cotton caused little or no deterioration in its strength.

CHAPTER XI.

CHEMICAL PROPERTIES OF COTTON; CELLULOSE.

I. Chemical Constitution.—In its chemical composition cotton, in common with the other vegetable fibres, consists essentially of **cellulose.** On the surface there is a protecting layer of more or less **wax** and **oily matter**, and also in the fibre there is a trace of **pigment**, which in some varieties of cotton becomes quite emphasized. The removal of these substances is the object of the boiling-out and bleaching process to which cotton is subjected prior to its dyeing and printing. In reality the purified cotton fibre as it exists in bleached material is practically pure cellulose, and this compound alone appears to be essential to its structural organization.

The **natural impurities** present in the raw cotton fibre amount to about 4 to 5 per cent., and consist chiefly of pectic acid, coloring-matter, cotton-wax, cotton-oil, and albuminous matter. The fibre gives about 1 per cent. of ash on ignition.* The **oil** present in the fibre appears to be identical with cottonseed-oil, and is probably obtained from the seed to which the fibre is attached. The **cotton-wax** serves as a protective coating for the fibre and makes it water-repellent, as is evidenced by the long time it requires for raw cotton to be wetted out by simply steeping in water. This wax appears to be closely analogous to carnaüba wax; it is not soluble in alkalies, though it may be gradually emulsified by a long-continued boiling in alkaline solutions, on which

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* Bowman is of the opinion that considerable stress should be laid on the fact that the cotton fibre contains about 1 per cent. of mineral matter as an integral part of its constitution, and this no doubt has considerable influence on its structure and properties.

fact is based the "boiling-out" of cotton by the ordinary methods. Cotton-wax, however, appears to be readily soluble in sulphated oils, such as Turkey-red oil, and hence cotton may be rapidly and thoroughly wetted out by using a solution of such an oil. The coating of wax over the cotton fibre appears to influence its spinning qualities to a certain extent, as it requires, for instance, a rather elevated temperature to successfully spin fine yarns, in order probably to soften the waxy coating of the fibre.*   The fatty acid present in cotton-wax has been found to be identical with margaric acid.   According to Dr. Schunck, American cotton contains about 0.84 per cent. of fatty matters, whereas East Indian cotton contains only 0.337 per cent.

Analysis of cotton-wax shows it to consist of the following:

	Per Cent.
Carbon	80.38
Hydrogen	14.51
Oxygen	5.11

It fuses at 85.9° C., and solidifies at 82° C., hence it bears a close analogy to both cerosin, or sugar-cane wax, and carnaüba wax.

The **coloring-matter** of cotton has been investigated and has been found to consist of two organic pigments, the one easily soluble in alcohol and the other dissolved only by boiling alcohol. According to Schunck, the composition of these bodies from Nankin cotton is as follows:

	A. Soluble in Cold Alcohol, Per Cent.	B. Insoluble in Cold Alcohol, Per Cent.
Carbon	58.22	57.70
Hydrogen	5.42	5.60
Nitrogen	3.73	4.99
Oxygen	32.63	31.71

---

* As the temperature falls the oily wax tends to become stiff and gummy, and prevents the proper drawing of the fibre; while its presence among the thin laminations of the cell-walls gives a greater elasticity to the fibre, and renders it less liable to sudden rupture.   The gradual drying-up of the more volatile portions of this oil in the fibre, leaving the remaining portion thicker and stiffer, may also, and probably does, account for the fact, noticed by most spinners, that new-crop cotton seems to work better and makes less waste than cotton harvested as the season advances. (Bowman, *Cotton Fibre*, p. 55.)

The composition of the analogous coloring-matters in American cotton is practically identical with the above.

Pectin compounds form the greater portion of the impurities present in cotton, and are probably rather complex in nature.

The quantity of **ash** (mineral matter) in raw bale-cotton will average considerably higher than that obtained from the purified fibre; this is due to adhering sand and dust which are nearly always present. The following table shows the amount of ash contained in samples of different varieties of cotton: *

	Per Cent.
Dharwar	4.16
Dhollerah	6.22
Sea-island	1.25
Peruvian (soft)	1.68
" (rough)	1.15
Bengal	3.98
Broach	3.14
Oomrawuttee	2.52
Egyptian (brown)	1.73
" (white)	1.19
Pernambuco	1.60
American	1.52

When the amount of ash is found to be over 1 per cent., the excess may be considered as mechanically attached sand and dust. The true ash of the cotton fibre consists principally of the carbonates, phosphates,† chlorides, and sulphates of potassium,

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* Monie (*The Cotton Fibre*) gives a table showing the percentage of sand or mineral matter contained in bales of commercial cotton as they arrive at Liverpool.

Sea-island	1.10	Upland	2.10
Rough Peruvian	1.25	Bahia	2.16
Gallini Egyptian	1.25	Hingunghat	2.33
Brown Egyptian	1.60	Broach	2.58
Orleans	1.60	Oomrawuttee	2.93
White Egyptian	1.75	African	3.2
Smooth Peruvian	1.80	Dhollerah	4.10
Pernambuco	1.98	Comptah	4.18
Texas	2.10	Bengal	5.3

It is to be presumed that Monie did not include in the above figures the amount of mineral matter in cotton as obtained from the ash of the purified fibre, but that his figures represent the sand or other foreign mineral matter mechanically held in the baled cotton.

† According to Calvert (*Jour. prakt. Chem* 1869, p. 122), cotton samples

calcium, and magnesium, as is exhibited by the following analysis of Dr. Ure:

	Per Cent.
Potassium carbonate	44.80
" chloride	9.90
" sulphate	9.30
Calcium phosphate	9.00
" carbonate	10.60
Magnesium phosphate	8.40
Ferric oxide	3.00
Alumina and loss	5.00

The analyses of Davis, Dreyfus, and Holland, reported as a mean from twelve different varieties of cotton, show a little difference from the above analysis, especially in having present sodium carbonate as one of the constituents. The mean of these analyses is given as follows:

	Per Cent.
Potassium carbonate	33.22
" chloride	10.21
" sulphate	13.02
Sodium carbonate	3.35
Magnesium phosphate	8.73
" carbonate	7.81
Calcium carbonate	20.26
Ferric oxide	3.40

The **albuminous** or nitrogenous matter present in cotton is only of very small amount, and doubtless consists of protoplasmic residue. Different varieties of cotton, on analysis, show the following percentages of nitrogen; some of this, however, may be derived from mineral nitrates which may be present in slight amount in the fibre (Bowman):

	Per Cent Nitrogen.
American	0.030
Sea-island	0.034
Bengal	0.039
Rough Peruvian	0.033
Egyptian (white)	0.029
" (brown)	0.042
Mean	0.0345

from different countries contain the following percentages of phosphoric acid soluble in water:

Egypt	0.055	Surat	0.027
New Orleans	0.049	Carthagena	0.035 to 0.050
Bengal	0.055	Cyprus	0.050

Analyses conducted by the U. S. Department of Agriculture give the average amount of nitrogen present in cotton as 0.34 per cent. As this differs very considerably from that obtained by Bowman, it may be possible that the values of the latter must be multiplied by ten to obtain the correct figure.

Church and Müller have made careful analyses of raw cotton with the following results: *

	I.	II.
Cellulose	91.15	91.35
Hygroscopic water	7.56	7.00
Wax and fat	0.51	0.40
Nitrogen (protoplasm)	0.67	0.50
Cuticular tissue	.....	0.75
Ash	0.11	0.12

2. Cellulose.—This is one of the most important of the naturally occurring chemical compounds, as it forms the basis of all vegetable tissue. Chemically it consists of carbon, hydrogen, and oxygen, and has the empirical formula $C_6H_{10}O_5$.† It belongs

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* *Bulletin No. 33* (U. S. Dept. Agric.) gives the following analysis of the cotton fibre, representing the average of a number of tests:

FERTILIZING CONSTITUENTS.

	Per Cent.
Water	6.07
Ash	1.37
Nitrogen	0.34
Phosphoric acid	0.10
Potash	0.46
Soda	0.09
Lime	0.19
Magnesia	0.08
Ferric oxide	0.02
Sulphuric acid	0.6
Chlorin	0.07
Insoluble matter	0.05

PROXIMATE CONSTITUENTS.

Water	6.74
Ash	1.65
Protein	1.50
Fibre (cellulose)	83.71
Nitrogen-free extract	5.79
Fat	0.61

† The cellulose of all vegetable tissues, even in a highly purified condition, appears to contain a small amount of mineral constituents, apparently forming

to a class of bodies known as *carbohydrates*, and is closely related
to the starches,* dextrins, and sugars. Chemically considered,
these compounds must all be regarded as alcohols containing
aldehydic and ketonic groups. The word " cellulose " must not
be taken as signifying a simple definite substance of unvarying
properties, but rather as a generic term including quite a number
of bodies of similar chemical nature. Like starch and other
complex carbohydrates of organic physical structure, cellulose
will vary somewhat in its properties, depending upon its source
or derivation. As a class the celluloses exhibit certain chemical
characteristics, by means of which they may be distinguished
from associated bodies of allied chemical constitution. Physically
they are colorless amorphous substances capable of withstanding
rather high temperatures without decomposition. They are
insoluble in nearly all of the usual solvents, but dissolve more
or less completely in an ammoniacal solution of copper oxide
(Schweitzer's reagent).† Solution in this latter reagent appparently

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an integral or organic portion of the fibre structure. The amount of ash, for
instance, obtained from bleached cotton is about 0.1 to 0.4 per cent. Even
"Swedish" filter-paper, which has been treated with hydrochloric and hydrofluoric
acids for the removal of inorganic constituents, will still contain from 0.03 to
0.05 per cent. of ash.

* Though cellulose appears to be somewhat analogous to these bodies, it never-
theless differs from them in its much greater resistance to the hydrolytic action
of acids, alkalies, and enzymes. The latter reagents readily split up the starches
into simpler bodies; but no such reaction, through artificial means at least, has
been observed in the case of cellulose. That such a reaction, however, takes
place in the tissues of the growing plant there is no doubt.

† Cross and Bevan make the following remarks respecting this reagent: The
solutions of cuprammonium compounds generally, in the presence of excess
of ammonia, attack cellulose rapidly in the cold, forming a series of gelatinous
hydrates, passing ultimately into fully soluble forms. The solutions of the pure
cuprammonium hydroxide are more active in producing these effects than the
solutions resulting from the decomposition of a copper salt with excess of ammonia.
Two methods are in common use for the preparation of these solutions, which
should contain 10 to 15 per cent. of ammonia and 2 to 2.5 per cent. of copper
as the oxide. (1) Hydrated copper oxide is prepared by precipitating a solu-
tion of copper sulphate of 2 per cent. strength with a slight excess of a dilute solu-
tion of sodium hydrate. The precipitate is washed until it is entirely free from
alkali. The original solution in which the solution takes place, as well as the
water used in washing, should contain a small quantity of glycerol. The washed
precipitate is well drained, and then mixed with a quantity of a 10 per cent. solu-

takes place without decomposition, as the cellulose may be repre-
cipitated unchanged therefrom by the addition of acids and
various salts. In order to obtain pure cellulose for chemical
purposes, it is customary to treat cotton successively with dilute
caustic alkali, dilute acid, water, alcohol, and ether.* The re-
sult of this treatment is to remove all foreign and encrusting
materials from the raw fibre, and possibly also to remove the
thin, external cuticular membrane which may be chemically
different from the rest of the tissue. The specific gravity or
density of cellulose as obtained in the usual manner is about 1.5,
and this also represents the density of cotton and most other
plant fibres. Chemically considered, cellulose is a derivative
of the open-chain or paraffin series of hydrocarbons, and further-
more it exhibits the reactions of a saturated compound. As
with the other carbohydrates, chemists have found it a matter
of great difficulty to ascertain even approximately the true mo-
lecular formula of cellulose. Though its empirical formula is
$C_6H_{10}O_5$, this in no way represents the true molecular complexity

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tion of glycerol, in contact with which it may be preserved unchanged in stoppered
bottles. When desired for use, the oxide is washed free from glycerol and dis-
solved in ammonia water (of 15 to 20 per cent strength). (2) Metallic copper,
in the form of sheet or turnings, is placed in a cylinder and covered with strong
ammonia; atmospheric air is caused to bubble through the column of liquid
at a rate calculated to 40 times the volume of the liquid used per hour. In
about six hours a liquid of the requisite composition is obtained. Solutions con-
taining 5 to 10 per cent. of cellulose are readily prepared by digestion in the cold
with 10 to 20 times the weight of cuprammonium solution, a rather ropy or gelat-
inous solution being obtained. The cellulose is readily precipitated from the
solution: (*a*) by the addition of neutral dehydrating agents, such as alcohol,
sodium chloride, and other salts of the alkalies, and (*b*) by the addition of acids,
in which case the cellulose is precipitated in the pure state, or free from copper
oxide.

* Cross and Bevan recommend the following procedure in the isolation of
pure cellulose in the study of the vegetable fibres: (*a*) The fibrous raw material
is boiled with a dilute (1 to 2 per cent.) solution of caustic soda, and, after thorough
washing, is (*b*) exposed in the moist state to an atmosphere of chlorin gas; (*c*) it
is again treated with boiling alkali. By such treatment the "non-cellulose"
constituents of most vegetable fibres are removed, and a residue of pure cellulose
is obtained. A subsequent slight treatment with a dilute solution of chloride
of lime for the removal of traces of coloring-matters, and a final washing with
alcohol and ether completes the purification.

of the substance.* From a study, however, of its various synthet-
ical derivatives, with special reference to its esters, such as the
acetates, benzoates, and nitrates, the provisional formula of
$C_{12}H_{20}O_{10}$ has been given to the cellulose molecule. The nature
and position of the various organic groups present in this mo-
lecular formula, however, have yet to be explained.†

* There has been a considerable amount of speculation among chemists as
to the chemical nature and constitution of cellulose, but there has been so little
experimental data on which to frame an intelligent theory, that most of these
speculations are mere scientific guesswork, and have little more than a pro-
visional value. From the action of zinc chloride on cellulose it has been pre-
sumed that the cellulose molecule contains hydroxyl groups of such a nature
as to give it a salt-like property, and the solution of the cellulose in the zinc chloride
is supposed to be due to the formation of a kind of double salt. There also appears
to be a chemical reaction of limited degree between cellulose and dilute solutions
of caustic alkalies and mineral acids. According to Mills, the relative molecular
ratio of the absorption by cellulose of alkalies and acids is represented by
$10NaOH : 3HCl$. From this and other considerations, it would appear that
cellulose exhibits the properties of a feeble acid and of a still more feeble base.

† Vignon has proposed to give cellulose the following constitutional formula:
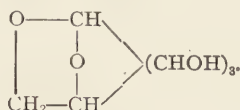
This is based on a study of the highest nitrate of cellulose and the decomposi-
tion of the nitrate by alkalies with formation of hydroxypyruvic acid. The struc-
ture given, however, is more or less hypothetical in nature, and needs experimental
confirmation in many particulars before it can be accepted without question
The older chemical configuration of cellulose given by Bowman,
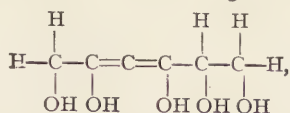
is without any experimental reason for its existence, and the idea that it contains
an unsaturated carbon grouping, $-C=C-$, has been proved erroneous. From
a study of the osazones of oxycellulose, Vignon has ascribed to this latter body
the constitutional formula of the group,
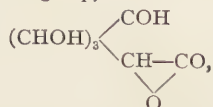
in union with varying proportions of residual cellulose.

The existence of a compound containing cellulose and sulphuric acid in the

In its chemical reactions cellulose is particularly inert, combining with only a few substances, and then only with great difficulty and under peculiar conditions. It is quite resistant to the processes of oxidation and reduction, and hydrolysis and dehydration.* Concentrated sulphuric acid dissolves cellulose with the production of a viscous solution; dilution with water causes the precipitation of an amorphous substance known as *amyloid*, a starch-like body having the formula $C_{12}H_{22}O_{11}$, and like starch it is colored blue with iodin. On this reaction is based the method of testing for cellulose, by applying sulphuric acid and iodin. On boiling with dilute sulphuric acid, cellulose is converted into dextrin and glucose. On heating with acetic anhydride to 180° C., cellulose is converted into an acetyl derivative having the formula $C_{12}H_{14}O_4(OCOCH_3)_6$.† By the moderated action of concentrated acids and various acid salts, cellulose appears to undergo a process of hydration, being converted into a friable amorphous body known as *hydrocellulose* or more properly *hydrated cellulose*.‡ This reaction is of importance

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proportion $4C_6H_{10}O_5$ to H_2SO_4 is put forward as a proof that in its reactions cellulose behaves like a complex molecule of at least 24 carbon atoms. (See Cross, Bevan, and Briggs, *Berichte*, 1905, p. 1859.)

* This high degree of resistance to hydrolysis (alkaline) and oxidation belongs only to cotton cellulose and to the group of which it is the type, and which includes the cellulose of flax, ramie, and hemp. A large number of celluloses, on the other hand, are distinguished by considerable reactivity, due to the presence of "free" carbonyl groups, and are therefore more or less easily hydrolyzed and oxidized. The celluloses of the cereal straws and esparto grass are of this type, and hence the relative inferiority of the papers into the composition of which they enter. (Cross and Bevan, *Jour. Chem. Soc.*, 1894, p. 472.)

† Cellulose does not react directly with acetic anhydride, but at the temperature above given and with six times its weight of the anhydride it gives the derivative having the above formula, and which may be called the triacetate. With a smaller quantity of acetic anhydride, a mixture of lower acetates is obtained which are insoluble in glacial acetic acid. The triacetate is readily soluble in this acid, however, and also in nitrobenzene. Its solutions are very viscous. Regenerated cellulose, prepared by precipitation of viscous solutions, reacts with acetic anhydride directly, and gives what appears to be the tetracetate. For further remarks concerning the acetylation of cellulose see Cross and Bevan, *Cellulose* and *Researches on Cellulose*.

‡ The formula suggested for hydrocellulose is $C_{12}H_{22}O_{14}$. Sthamer (Hamburg) prepares hydrocellulose by treating cotton (or other form of cellulose)

in the carbonizing process for removing vegetable matter from woolen goods.

A concentrated solution of zinc chloride will dissolve cellulose on heating and digesting for some time.*   This solution has been employed industrially for the preparation of cellulose filaments, which are subsequently treated with hydrochloric acid and washed for the purpose of removing the zinc salt; the thread is then carbonized and is employed for the carbon filament of incandescent electric lamps.†   A concentrated solution of zinc chloride in hydrochloric acid dissolves cellulose quite rapidly and in the cold.‡   This latter method is useful in the laboratory for the study of celluloses, but as yet has received no technical application. By means of this solution it has been shown that the cellulose molecule does not contain any unsaturated carbon groups, for it exhibits no absorption of bromin. A solution of a ligno-cellulose, on the other hand, gives a marked bromin absorption, thus showing evidence of unsaturated carbon groups.

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mixed with potassium chlorate with hydrochloric acid at a temperature of 60°–70° C. The product obtained in this manner is in the form of a white powder very resistant to acids and alkalies.

* Cross and Bevan recommend the following method for preparing this solution of cellulose: 4 to 6 parts of anhydrous zinc chloride are dissolved in 6 to 10 parts of water, and 1 part of bleached cotton is then stirred in until evenly moistened.   The mixture is digested for a time at 60° to 80° C., when the cellulose is gelatinized; the solution is completed by heating on a water-bath and stirring from time to time, and replacing the water which evaporates.   In this manner a homogeneous syrup is obtained.   This solution of cellulose is entirely decomposed by dilution, the cellulose being precipitated as a hydrate in combination with zinc oxide.   On washing this precipitate with hydrochloric acid a pure cellulose hydrate is obtained, the quantity recovered being approximately equal to the original cellulose taken.   When precipitated by the addition of alcohol, a compound of cellulose and zinc oxide is obtained, with 18 to 25 per cent. of ZnO, and having the approximate molecular ratio of $2C_6H_{10}O_5 : ZnO$.

† The threads for the production of the carbon filaments are prepared by forcing the syrupy solution of cellulose through fine glass orifices into alcohol, whereby the cellulose is precipitated in a continuous thread.

‡ The reagent is prepared by dissolving one part of zinc chloride in twice its weight of concentrated hydrochloric acid.   If the solution of cellulose obtained with this solvent is diluted when fresh, the cellulose will be precipitated unaltered; but if the solution is allowed to stand, the cellulose is rapidly resolved into decomposition products, such as dextrin, etc., which are entirely soluble in water.

Cellulose is colored a deep violet by a solution of zinc chloriodide, and this reagent is employed as a delicate test for the presence of cellulose. The reagent may be best prepared by using 90 parts of a concentrated solution of zinc chloride, adding 6 parts of potassium iodide in 10 parts of water, and iodin until saturated.

When cellulose is treated with concentrated caustic alkalies, it undergoes a change which may be crudely referred to as " mercerization," whereby a compound known as *alkali-cellulose* is formed, in which the molecular ratio of alkali to cellulose may be given as $C_{12}H_{20}O_{10}$: NaOH. When this body is treated with carbon disulphide, a substance known as *cellulose thiocarbonate* or *xanthate* is formed. This body yields a very viscous solution with water and has been utilized for various technical purposes (see *viscose*, chapter xiii).* Cellulose xanthate undergoes spontaneous decomposition, splitting up into cellulose hydrate, alkali, and carbon disulphide; this cellulose hydrate is also known as *regenerated cellulose*.† This substance can also be precipitated by the

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* The best conditions for the preparation of viscose is to use the reagents in the following molecular proportions: $C_6H_{10}O_5$: 2NaOH: CS_2 (with 30 to 40 H_2O).

The reaction is carried out in practice by treating bleached cotton (though other forms of cellulose, such as purified wood-pulp, may also be used) with excess of a 15 per cent. solution of caustic soda, then squeezing out the excess of liquor, but leaving in the fibre about three times its weight of the solution. The mass is then mixed with about 50 per cent. (on the weight of the cotton) of carbon disulphide, and allowed to stand in a covered vessel for about three hours at the ordinary temperature; after which sufficient water is added to cover the mass, and the hydration allowed to proceed for several hours longer. The mass is then stirred up and a homogeneous solution is obtained which may be diluted to any desired degree. The solution thus prepared has a yellow color, which, however, is due to the presence of tri-thiocarbonates which occur as by-products in the reaction. By treating the solution with a saturated solution of common salt or with alcohol, pure cellulose thiocarbonate is precipitated as greenish white flocculent mass, which may be redissolved in water, giving a colorless or faintly yellow-colored solution. On the addition of various metallic salts to this solution, the corresponding xanthates may be precipitated. With iodin a precipitate of dioxy-thiocarbonate is formed, which may be said to take place in accordance with the following equation:

$$CS\begin{matrix}/OX\\\\\backslash SNa\end{matrix}+\begin{matrix}XO\backslash\\\\NaS/\end{matrix}CS+I_2=2NaI+CS\begin{matrix}/OX-XO\backslash\\\\\backslash S\text{------}S/\end{matrix}CS.$$
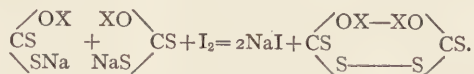
† When this decomposition takes place in solutions containing more than one

addition of various salts, such as ammonium chloride. Alkali-cellulose also reacts with benzoyl chloride, with the formation of *cellulose benzoate*.* Another ester of cellulose is the *acetate*, which can be made by the action of acetic anhydride on cellulose heated in a sealed tube †—regenerated cellulose can also be employed. By varying the conditions of treatment a number of different acetates have been prepared.‡ The *tetracetate* has received a number of commercial applications for the production of films and for waterproofing. By the action of nitric acid under vary-ing conditions, a number of *cellulose nitrates* (improperly called nitrocelluloses) have been prepared, which have received numer-ous applications (see *pyroxylin*). Concentrated sulphuric acid reacts with cellulose to form at first a *cellulose sulphate;* this

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per cent. of cellulose, a firm jelly of coagulated cellulose is produced of the same volume as the original solution. A solution containing as much as 10 per cent. of cellulose decomposes to a substantial solid of hydrated cellulose which gives up its water with extreme slowness. The cellulose regenerated in this manner is probably in the "colloidal" form.

* See Cross and Bevan, *Cellulose*, p. 32, and *Researches on Cellulose,* p. 34, etc.

† According to a recent patent (Eng. Pat. 1905, No. 9998), an almost theoreti-cal yield of cellulose tetracetate may be obtained by conducting the acetylation in the presence of methyl sulphate; the process given being as follows: 30 parts of cotton are treated in a bath with 70 parts of acetic anhydride, 120 parts of glacial acetic acid, and 3 parts of dimethyl sulphate until solution is almost complete. The solution is then filtered and the filtrate is poured into a large quantity of water, whereupon the acetate of cellulose is precipitated.

‡ The acetate of cellulose may be prepared by heating a mixture of hydrocel-lulose, acetic anhydride, and sulphuric acid to 60°–70° C. The acetate of cellulose so obtained is soluble in ether and chloroform (Lederer). At Sthamer's chemical works (Hamburg) acetate of cellulose is prepared by heating a mixture of hydrocellu-lose, acetic acid, acetyl chloride, and sulphuric acid to 65°–70° C. An acetate of cellulose soluble in alcohol and pyridin is obtained by heating a mixture of cel-lulose, acetic anhydride, and sulphuric acid to 45° C. (Farbenfabriken vorms. Fr. Bayer & Co. of Elberfeld). Miles and Pierce (Brooklyn) obtain it by heating a mixture of cellulose, acetic anhydride, acetic acid, and sulphuric acid to 70° C. Landsberg substitutes phosphoric acid for sulphuric acid in the preceding mix-ture. Acetate of cellulose has also been prepared by warming a mixture of cellulose, acetic acid, acetic anhydride, and a mixture of phenol-sodium sulphonate and phenol-sulphonic acid, or of sodium naphtholate and naphthol-sulphonic acid (Little, Walker & Mork, Boston). Cellulose may also be acetylized by means of a mixture in nitrobenzene solution of acetyl chloride and chloride of zinc or magnesium, in the presence of pyridin or quinolin (Wohl, Charlottenburg).

subsequently undergoes decomposition with a consequent hy-drolysis of the cellulose molecule and the formation of amy-loid.

Aceto-sulphates of cellulose have been prepared by the joint action of acetic acid, acetic anhydride, and sulphuric acid on cellulose.*

Although cellulose is comparatively inert to the majority of chemical reagents, it has a powerful attraction for certain salts held in solution and will absorb them completely. This power of absorption is especially marked towards salts of vanadium, these being completely separated from solutions containing only one part of the salt per trillion.

Besides cellulose itself, there are a number of derived sub-stances which are known as *compound celluloses*. These are classified into three general groups:

(*a*) *Pectocelluloses*, related to pectin compounds of vegetable tissues; represented among the fibres by raw flax; resolved by hydrolysis with alkalies into pectic acid and cellulose.

(*b*) *Lignocelluloses*, forming the main constituent of woody tis-sue and represented among the fibres by jute; resolved by chlorina-tion into chlorinated derivatives of aromatic compounds soluble in alkalies and cellulose.

(*c*) *Adipocelluloses*, forming the epidermis or cuticular tissue of fibres, leaves, etc.; resolved by oxidation with nitric acid into derivatives similar to those of the oxidation of fats and cellulose.

Frémy groups the various celluloses and their derived bodies in the following manner, which is based on a chemical classifica-tion: (*a*) *celluloses*, including normal cellulose, paracellulose, and metacellulose; (*b*) *vasculose* (identical with lignocellulose); (*c*) *cutose;* (*d*) *pectose.*

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* See Cross, Bevan & Briggs, *Berichte*, 1905, p. 1859. For the preparation of what these chemists term the normal cellulose aceto-sulphate, to which the formula $4(C_6H_7O_2).(SO_4).(C_2H_3O_2)_{10}$ is ascribed, 16 grams of dry cotton are stirred for 20 minutes at 30° C. in 100 cc. of a mixture of equal parts of glacial acetic acid and acetic anhydride containing 4.5 per cent. by weight of sulphuric acid. After standing for one hour, a homogeneous, translucent, and viscous solu-tion is obtained, which is precipitated on being poured into water as a semi-trans-lucent, gelatinous hydrate, which is soluble in alcohol. By using less sulphuric acid the product obtained is insoluble in alcohol.

3. Chemical Reactions of Cotton.—Cotton itself presents the same general reactions and chemical properties as cellulose. It is capable of standing rather **high temperatures** without decomposition or alteration; though it appears that when cotton is subjected to a temperature of 160° C., whether moist or dry heat, a dehydration of the cellulose takes place, accompanied by a structural disintegration of the fibre. This fact has an important bearing on the singeing, calendering, and other finishing processes where high temperatures are used. At 250° C. cotton begins to turn brown; and when **ignited in the air** it burns freely, emitting an odor faintly suggesting acrolein, but without the characteristically empyreumatic odor of burning animal fibres. When subjected to **dry distillation** cotton is decomposed into methane, ethane, water, methyl alcohol, acetone, acetic acid, carbon dioxide, pyrocatechol, etc. Though unaltered and insoluble in boiling water, when heated with water under pressure to 200° C. it is dissolved with complete decomposition.

Like cellulose itself, cotton is dissolved by **Schweitzer's reagent**, though under ordinary conditions its solution is a rather slow process. In order to dissolve cotton most effectively in ammoniacal copper oxide, it is recommended to treat the raw cotton with a strong solution of caustic soda until the fibres swell up and become translucent; squeeze out the excess of liquid, and wash the cotton with strong ammonia water; then treat with the solution of ammoniacal copper oxide and the cotton will be found to dissolve quite rapidly. This solution may furthermore be filtered and diluted with water. The use of this solution for the production of lustra-cellulose filaments has received some degree of commercial application (see Pauly silk, chapter xiii). This reaction is also utilized in the preparation of a fabric known as *Willesden canvas;* the cotton fabric is passed through a solution of ammoniacal copper oxide, whereby the surface becomes coated with a film of gelatinized cellulose containing a considerable amount of copper oxide. On subsequent hot pressing this film is fixed on the surface of the material as a substantial coating, which is said to make the canvas water-proof and render it unaffected by mildew and insects.

Concentrated solutions of **zinc chloride** are capable of dissolving cotton, but only after a prolonged digestion at about 100° C., though by first treating the cotton with caustic alkali the solution takes place in the cold. The product so obtained has received several industrial applications; *vulcanized fibre* is prepared by treating paper with a concentrated solution of zinc chloride,* and the resulting gelatinous mass is manufactured into various articles, such as blocks, sheets, etc. The chief difficulty encountered is the subsequent removal of the zinc salt, which necessitates a very lengthy process of washing. The material may be rendered water-proof by a further process of nitration.† The solution has also been suggested for use as a thickening agent in calico-printing. Its use for the production of lustra-cellulose or artificial silk and incandescent-lamp filaments has also been attempted.

With **mineral acids** cotton exhibits practically the same general reactions as pure cellulose. **Concentrated sulphuric acid** produces amyloid in the manner already mentioned, and this fact is utilized in the preparation of what is known as *vegetable parchment.* Unsized paper is rapidly passed through concentrated sulphuric acid, then thoroughly washed and dried. The effect of this treatment is to cause the formation on the surface of the paper of a layer of gelatinous amyloid, which on subsequent pressing and drying gives a tough membranous surface to the paper resembling true parchment. This renders the paper grease-proof and water-proof, and increases its tensile strength considerably. *Artificial horse-hair* has been prepared in a similar manner from certain Mexican grasses. These latter are steeped for a short time in concentrated sulphuric acid, and become parchmentized thereby, so that on being subsequently washed and combed they assume an appearance very much resembling horse-hair, and are said to possess even greater elasticity than

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* One part of paper is treated with four parts of zinc chloride solution of 65° to 75° Bé. until the fibres are partially gelatinized, when the sheets are then pressed together into very compact masses. (See Hofmann, *Handb. d. Papierfab.*, p. 170.)

† Hofmann, *ibid.*, p. 1703.

horse-hair itself. In place of strong sulphuric acid a solution of zinc chloride may be used with similar results. Amyloid appears also to be a product of natural plant growth, as its presence has been detected in the walls of vegetable cells; it may be recognized by giving a blue color with iodin.

Very **dilute solutions of sulphuric acid,** especially in the cold, have no appreciable action on cotton. But if the fibre is impregnated with such a solution and then allowed to dry it becomes tendered; this is owing to the gradual concentration of the acid in the fibre on drying. Elevated temperatures also cause the dilute acid to attack the fibre much more quickly and severely than otherwise.

In all dyeing and bleaching operations where the use of acid may be required, the above facts should always be borne in mind; the temperature of the acid baths should be not above 70° F., and the acid strength should not be more than 2 per cent. Where higher temperatures are necessary, organic acids should be substituted for mineral acids wherever possible. Acetic acid, for instance, is often used. Whenever cotton is treated with acid solutions or with salts of an acid nature, or which are liable to decompose with liberation of acid, all of the acid should be removed from the fibre or properly neutralized before drying, else the material will be tendered and probably ruined. The action of dilute acid on cotton is probably an hydrolysis of the cellulose molecule, with the formation of cellulose hydrate, causing a structural disorganization of the fibre.* **Hydrochloric acid** has an effect similar to sulphuric acid, and the same remarks concerning the use of this latter acid in connection with cotton also hold true for the former. **Strong nitric acid** has a somewhat different effect;† it completely decomposes cotton, in

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* The action of dilute mineral acids on cotton seems to be one of hydrolysis, whereby a molecular change occurs in the fibre substance. This hydrolytic action is supposed to result in the formation of a hydrate of cellulose, having the formula $2C_6H_{10}O_5 \cdot H_2O$. Acetic acid has but small hydrolytic action, and consequently has little action on cotton.

† The action of nitric acid on cotton fabrics appears to be a peculiar one. The following observations in this respect have been recorded by Knecht: Bleached calico steeped for fifteen minutes in pure nitric acid at 80° Tw., washed and

common with other forms of cellulose, oxidizing it to oxalic acid. When boiled with moderately concentrated nitric acid cotton is converted into **oxycellulose,** a structureless, friable substance possessing a great affinity for basic dyestuffs.* When mixed with concentrated sulphuric acid, however, the action of nitric acid is totally different, the cellulose being converted into a nitrated body, though the physical appearance of the fibre is not appreciably altered. The exact nature of the nitrated compound will depend on the conditions of treatment. Several nitrated celluloses are known and possess commercial importance; they are classified under the general name of **pyroxylins.**† Gun-

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dried, showed a considerable contraction, amounting to about 24 per cent.; the tensile strength also increased 78 per cent. Unbleached yarn, treated in the same manner, also showed a considerable increase of tensile strength, and a proportional contraction in length. Weaker acids did not show these results, the fibre being tendered instead of being strengthened. Analysis proved that 7.7 per cent. of nitrogen was present, showing that about two molecules of the acid had combined with the cotton. The shrinkage, gain in strength, microscopical appearance, etc., of the treated material, all go to show that in addition to the nitration a mercerizing effect has been produced. This appears in the fact that the material exhibits a strongly increased affinity for many dyestuffs, especially the direct cotton colors and some of the acid dyes; while by reason of its not showing any increased affinity for the basic colors there is proof that oxycellulose has not been produced. This action of strong nitric acid on cellulose has been utilized for the preparation of toughened filter-papers which are required to stand high fluid pressures. The filter-paper is immersed in concentrated nitric acid for a brief period and then well washed.

* Oxycellulose appears to have the formula $C_{18}H_{26}O_{16}$. It dissolves in a mixture of nitric and sulphuric acids, and from the low number of hydroxyl groups reacting with the nitric acid, it may be concluded that the compound is both a condensed as well as an oxidized derivative of cellulose. Oxycellulose is soluble in dilute solutions of the alkalies, and, on heating, the solutions develop a deep-yellow color. When warmed with concentrated sulphuric acid it gives a pink color similar to that of mucic acid. In general it exhibits a close resemblance to the pectic group of colloidal carbohydrates. (See Cross and Bevan, *Cellulose,* p. 56.) It is probable that the oxidation products of cellulose obtained by different means do not all give the same oxycellulose; or, what is more probable, the oxycelluloses which have so far been studied are perhaps mixtures of various different bodies which have not yet been separated and isolated.

† The following descriptions of the different nitrated products of cotton cellulose have been adapted from Cross and Bevan, *Cellulose.* In the formulas given the cellulose unit group is taken as $C_{12}H_{20}O_{10}$.

Cellulose hexanitrate, or guncotton, $C_{12}H_{14}O_4(NO_3)_6$, is made by the use of 3 parts nitric acid of sp. gr. 1.5 and 1 part sulphuric acid of sp. gr. 1.84. The

cotton, a hexanitrated cellulose, is the most highly nitrated product,

cotton is immersed in this mixture for 24 hours at a temperature not above 10° C.; 100 parts of cellulose yield about 175 parts of the nitrate. This nitrate is insoluble in alcohol, ether, or in mixtures of both, in glacial acetic acid, or methyl alcohol; slowly soluble in acetone. Ordinary guncotton may contain as much as 12 per cent. of nitrates soluble in ether-alcohol mixture.

Cellulose pentanitrate, $C_{12}H_{15}O_5(NO_3)_5$, is prepared by dissolving guncotton (the hexanitrate) in nitric acid at 80° to 90° C., and precipitating by the addition of sulphuric acid after cooling to 0° C. The precipitate consists of the pentanitrate, and is purified by washing with water, then with alcohol, dissolving in ether-alcohol, and reprecipitating with water. The pentanitrate is insoluble in alcohol,.is slightly soluble in acetic acid, and readily so in ether-alcohol; by treatment with strong caustic potash it is converted into the dinitrate.

Cellulose tetra- and *tri-nitrates* (collodion pyroxylin) are formed simultaneously when cotton is treated with a more dilute acid and at higher temperatures, and for a shorter time than in the preparation of the hexanitrate. As these two nitrates are soluble to the same extent in ether-alcohol, acetic ether, and methyl alcohol, it is not possible to separate them. When treated with a mixture of concentrated nitric and sulphuric acids, they are both converted into penta- and hexanitrates; caustic potash and ammonia convert them into the dinitrate.

Cellulose dinitrate, $C_{18}H_{13}O_9(NO_3)_2$, is formed through a partial saponification of the higher nitrates by the action of caustic potash, and also by the action of hot dilute nitric acid on cellulose. The dinitrate is very soluble in ether-alcohol, acetic ether, and in absolute alcohol.

Vielle (*Compt. Rend.,* vol. 95, p. 132) has studied the nitration of cotton with different concentrations of acid with the following results:

Density of Nitric Acid.	Product Obtained.
1.502 } 1.497	Structural features of cotton preserved; soluble in acetic ether; not in ether-alcohol: $C_{24}H_{20}(NO_3H)_{10}O_{10}$.
1.496 1.492 1.490	Appearances unchanged; soluble in ether-alcohol; collodion cotton: $C_{24}H_{22}(NO_3H)_9O_{11}$, $C_{24}H_{24}(NO_3H)_8O_{12}$.
1.488 } 1.483	Fibre still unresolved; soluble as above, but solutions more gelatinous and thready: $C_{24}H_{26}(NO_3H)_7O_{13}$.
1.476 1.472 1.469	Dissolve cotton to viscous solution; products precipitated by water; gelatinized by acetic ether; not by ether-alcohol: $C_{24}H_{28}(NO_3H)_6O_{11}$.
1.463 1.460 1.455 1.450	Friable pulp; blued strongly by iodin in potassium iodide solution; insoluble in alcohol solvents: $C_{24}H_{30}(NO_3H)_5O_{15}$, $C_{24}H_{32}(NO_3H)_4O_{16}$.

and is used as a basis of many explosives. Soluble pyroxylin is a trinitrated cellulose; its solution in a mixture of alcohol and ether is called *collodion* and is employed in surgery and photography. Another derivative, supposed to be a tetranitrated cellulose, is also soluble in ether-alcohol, and its solution has been utilized for the production of lustra-cellulose filaments. By dissolving nitrated cellulose in molten camphor a substance known as *celluloid* is formed.

The action of **hydrofluoric acid** on cotton and other vegetable fibres appears to be a peculiar one; a transparent, tough, flexible water-proof material being obtained. The product does not appear to resemble parchment obtained by the action of sulphuric acid. It is used as an insulating material and for making the carbon filaments of incandescent electric lamps.

Organic acids in solution, even when moderately concentrated, do not appear to have any injurious action on cotton. The non-volatile acids, however, such as oxalic, tartaric, and citric acids, when allowed to dry into the fibre,* act much in the same manner as mineral acids, especially at elevated temperatures.† Acetic

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* The effect of certain acids on the strength of cotton is an important factor in printing. The following table shows the degree of weakening caused by various acids, strips of calico being printed with tragacanth pastes containing 20 grams of oxalic acid per litre, or an equivalent amount of the other acids, and in the first case exposed for four hours to the ordinary temperature, and in the second case steamed for one hour:

Acid.	I.	II.
Oxalic.	25 per cent.	25 per cent.
Tartaric.	5 " "	10 " "
Ortho-phosphoric.	1.5 " "	15 " "
Meta-phosphoric.	31.5 " "	35 " "
Pyro-phosphoric.	35.0 " "	35.5 " "
Phosphorous.	27 " "	28 " "

Under similar conditions sulphocyanic acid has but a very slight tendering effect on printed cotton, even under the influence of steaming, but under the influence of dry hot air its tendering action is greater than that of oxalic acid.

† The destructive action of these acids on the cotton fibre is, perhaps, not so much of a chemical nature as mechanical, it being caused by the acids crystal-lizing within the fibre and thus breaking the cell-wall. A dry heat, for instance, in connection with these acids is much more injurious than a moist heat, a fact

acid, however, being volatile, exerts no destructive action; hence this latter acid is particularly suitable for use in the dyeing and printing of cotton goods, where the use of an acid is requisite.*

Tannic acid, unlike other acids, exhibits quite an affinity for cotton, the latter being capable of absorbing as much as 7 to 10 per cent. of its weight of tannic acid from an aqueous solution. Advantage is taken of this fact in the mordanting of cotton with tannic acid and tannins for the dyeing and printing of basic colors. Cotton exhibits a similar attraction for tungstic acid; the expense of this latter compound, however, precludes its adoption as a mordanting agent.

Though acids, in general, have such an injurious action on cotton, **alkalies**, on the other hand, are harmless under ordinary conditions. Dilute solutions of either the carbonated or caustic alkalies, even at a boiling temperature, if air is excluded, have no injurious effect on cotton. In the **presence of air** alkaline solutions cause an hydrolysis of the cellulose in a manner similar to acids, with the result that the fibre is seriously weakened. The prolonged action of alkalies in the presence of air is an important one to bear in mind in the operations of bleaching, dyeing, or mercerizing. Boiling solutions of dilute alkalies dissolve or emulsify the waxy and fatty impurities encrusting the cotton fibre, hence these reagents are largely employed in the scouring of cotton goods.

The action of **alkaline solutions** at **high temperatures** (above 100° C.) on cotton appears, however, to be a destructive one. Tauss has shown that if cotton be digested with solutions of caustic soda under pressure, the fibre is attacked and converted

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which is of much importance in the drying of cotton prints, where the above-mentioned acids may have been used.

* Oxalic acid appears to have a peculiar effect on cotton; it has been noticed that if a piece of cotton cloth be printed with a thickened solution of oxalic acid, dried, and hung in a cool place for about twelve hours, and then well washed, the printed parts exhibit a direct affinity towards the basic dyes. The cotton so treated does not become greatly tendered or otherwise changed. Towards substantive dyes it exhibits considerably less attraction than ordinary cotton, while with alizarin dyes it is partially reactive. Tartaric and citric acids do not produce the same effect, nor does the neutral or acid oxalate of potassium.

into soluble products; the degree of decomposition depending on the pressure and the strength of the alkaline liquor, in accordance with the following table:

Pressure.	Strength of Alkali.	
	3 Per Cent. Na_2O.	8 Per Cent. Na_2O.
	Per Cent. of Cotton Dissolved.	
1 atmosphere.	12.1	22.0
5 atmospheres.	15.4	58.0
10 "	20.3	59.0

Solutions of **ammonia** do not act on cotton until quite high temperatures are reached. According to the experiments of L. Vignon, at 200° C. ammonia reacts with cotton cellulose, the result being the evident formation of an amido-cellulose compound, the product evincing a greatly increased degree of absorption for dyestuff solutions, especially for the acid coloring-matters, somewhat after the manner of animal fibres.

This action of **alkaline solutions** on cotton under **high pressure** has an important bearing on the bleaching of this fibre, where it is subjected to such action by boiling with alkalies in pressure kiers. This phase of the question does not appear to have received much attention from either the practical bleacher or the theoretical chemist, but it would seem to be worthy of some degree of intelligent research on the part of both.

Concentrated solutions of caustic alkalies have a peculiar effect on cotton; the fibre swells up, becomes cylindrical and semi-transparent, while the interior canal is almost entirely obliterated by the swelling of the cell-walls. There is a marked gain in weight and strength, while the affinity of the cotton for coloring-matters is materially increased. This effect was first noticed by John Mercer in 1844, and the reaction forms the basis of the modern process of **mercerizing**, under which title a more complete and extensive discussion of this reaction will be found. Solutions of **sodium sulphide** appear to have no immediate tendering action on cotton, even at a boiling temperature. If the

sodium sulphide is dried into the fibre after about six weeks, the cotton shows a loss in strength of from 10 to 20 per cent. Also, when sodium sulphide is dried into the fibre at 100° C., the tendering amounts to from 10 to 20 per cent. Cotton containing copper sulphide or iron sulphide shows no appreciable amount of tendering. When cotton is impregnated with **sulphur** and exposed to a damp atmosphere for several weeks, its tensile strength is reduced by about one-half. This is perhaps due to the oxidation of the sulphur into sulphurous and sulphuric acids.

If cotton, or other forms of cellulose, be treated with a concentrated solution of caustic soda to which a small amount of carbon disulphide has been added, the fibres swell up, become disintegrated, and finally form a gelatinous mass. This latter is soluble in a large amount of water, producing a very viscous solution, technically known as **viscose**. From this solution hydrocellulose may be precipitated by sulphurous acid gas, as well as by various other reagents. Precipitation also occurs by simply allowing the solution to stand for some time, in which case the hydrated cellulose separates out as a jelly-like mass. Viscose has received several commercial applications, among which may be mentioned more especially the use of its solutions for the preparation of lustra-cellulose filaments.

Though cotton does not show nearly the same degree of affinity for acids and alkalies as do the animal fibres, nevertheless it has been shown that cotton does absorb both acids and alkalies from their solutions, even when cold and dilute. The ratio of absorption appears to be 3 molecular parts of acid to 10 molecular parts of caustic alkali.* Vignon, by a study of the thermochemical reactions of cotton, has shown that when this fibre is treated with acids or alkalies a liberation of heat takes place,† from which fact it would appear that cotton exhibits in some degree the properties of a very weak acid and a still weaker base.

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* See p. 215.

† Vignon gives the following results in calories per 100 grams of cotton:

	KOH.	NaOH.	HCl.	H_2SO_4.
Raw cotton............	1.30	1.08	0.65	0.60
Bleached cotton........	2.27	2.20	0.65	0.58

Strong **oxidizing agents**, such as chromic acid, permanganates, chlorin, etc., in concentrated solutions, readily attack cotton, converting it into oxycellulose. This substance appears to possess an increased affinity for dyestuffs, but it is of a structureless and brittle nature, hence its formation greatly tenders the fibre. It is said that oxycellulose is indifferent towards the tetrazo dyestuffs; and, in consequence, these may be employed for the purpose of detecting the presence of oxycellulose in cotton materials.

In its action towards various **metallic salts** cotton is very neutral, thereby differing considerably from both wool and silk. If the salts, however, are present in a very basic condition, cotton is capable of decomposing them and loosely fixing the metallic hydroxide. Many salts, especially those of an acid nature, will tender the cotton fibre, probably due to the liberation and drying-in of the acid. Consequently, such salts should be avoided or used very carefully with cotton, and any excess should be thoroughly eliminated by subsequent washing before the material dries.

In its behavior towards **coloring-matters** cotton differs most markedly from the animal fibres. Of the natural dyestuffs, only a few color the cotton fibre without a mordant; with the coal-tar colors, cotton exhibits no affinity for most of the acid or basic dyes, and these can only be applied on a suitable mordant. The substantive colors, however, are readily dyed on cotton, in a direct manner, and since their introduction the methods of cotton dyeing have been practically revolutionized.

There has been much discussion as to whether the phenomena of dyeing with reference to cotton are of a physical or chemical nature. Unlike the animal fibres, cotton does not possess groups of a very distinctly active chemical nature; that is to say, it cannot be said to noticeably exhibit either acid or basic properties. The only groups in cotton cellulose which may be considered chemically active are the hydroxyl groups. These can be rendered inactive by acetylation, and it has been shown * that cotton so

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* Suida, *Färber-Zeit.*, 1905

treated does not exhibit any difference in dyeing properties from ordinary cotton, and this leads us to the assumption that in the case of cotton, the phenomena of dyeing rest on a physical dissociation of the dyestuff molecule determined by the fibre; that is to say, the process of dyeing with reference to cotton must be attributed (in great measure at least) to the action of dissociation, dissolution, and capillarity; in other words, to purely physical or physico-chemical causes; and purely chemical reactions, if they come into play at all, are of secondary importance.

Though resistant to the action of moths and insects in general, cotton is liable to undergo fermentation,* as is evidenced by the formation of mildew † on cotton fabrics stored in damp places.

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* According to Knecht (*Jour. Soc. Dyers & Col.*, 1905, p. 189), human saliva has a peculiar and distinct effect on cotton. His experiments show that a piece of bleached calico, saturated with saliva, will absorb considerably more dyestuff on dyeing with substantive colors than untreated cotton. This is not due to mucus, or to any of the salts contained in the saliva, but probably to the enzyme ptyalin, since the saliva loses the power of producing the effect after boiling. Of other enzymes, diastase was also found to have some action, though very slight. This action of saliva on cotton may explain some faults arising in dyeing cotton pieces.

† Mildew does not appear as often on white and colored as on gray (unbleached) cloth, which, being sized, is much more liable to this defect. The essential conditions for the production of mildew appear to be (1) dampness, (2) lack of fresh air, (3) the presence of certain bodies (such as flour, etc.) suitable as foods for the fungi. The more common varieties of mildew are:

(1) Green mildew, a common form generally due to *Penicillium glaucum* and *Aspergillus glaucus*, which are closely allied, but which are distinguishable from the way in which the spores are attached. In the former the spores are on branches, while in the latter they are attached to the head; they grow rapidly and generally form rather large patches.

(2) Brown mildew is frequently found on cloth, and is due to various species of fungi, of which *Puccinia graminis* is perhaps the most common. This and the brick-red mildew noticed below are frequently mistaken for iron stains, the color of which they closely resemble. They are easily distinguished by the manner in which they occur in small spots, often of a ring shape, and they do not give the Prussian-blue test.

(3) Brick-red mildew is not very frequent and the fungus which causes it has not been definitely recognized; it grows rapidly at first, but has no great vitality and after a time the development stops.

(4) Yellow mildew, a common variety occurring in large irregular patches and spots. Not requiring much air for its development, it extends much more into

Though this fermentation is often induced by the presence of more or less starchy matter contained in the sizing materials used in finishing the goods, yet pure cellulose itself can also be fermented, and Omeliansky has succeeded in isolating the particular bacillus which destroys cellulose.

There has been much discussion as to whether the various treatments to which cotton is subjected during the process of bleaching has any deleterious effect on the strength of the fibre. In this connection O'Neill gives the following interesting results, made to determine the tensile strength of cotton-threads before and after bleaching:

	Average Weight Required to Break a Single Thread.	
	Before Bleaching.	After Bleaching.
No. 1 cloth, weft-threads.	1714 grains	2785 grains
No. 1 " warp-threads.	3140 "	2020 "
No. 2 " "	3407 "	3708 "
No. 2 " "	3512 "	4025 "

It will be noticed that in two cases out of three the warp-threads are stronger than before, and it may be safely concluded that the tensile strength of cotton yarn is not injured by careful though thorough bleaching, and probably it may be strengthened by the wetting and pressure, causing a more complete and effective binding of the separate cotton fibres, the twisting together of which makes the yarn stronger.

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the folds of the cloth than do most of the other kinds. It is a yellow variety of the *Aspergillus glaucus* (*Eurotium*) and may also be *Oidium aurantiacum*.

(5) Black mildew, due often to fungi belonging to the genus *Tilletia*, is occasionally found; it is very rapid in growth.

(6) Purple mildew is rare.

(7) Bright pink mildew is also rare.

(*Textile Mercury*, 1906.)

CHAPTER XII.

MERCERIZED COTTON.

1. Mercerizing is a term applied to that process whereby cotton is treated with concentrated caustic alkalies. In its strictest significance, however, it refers most directly to the process of giving cotton a high degree of lustre by subjecting it simultaneously to the chemical action of caustic alkalies and the mechanical action of tension sufficient to prevent contraction. The process is named from John Mercer, who first discovered the effect of strong solutions of caustic alkalies on cotton in the year 1844. It was not until the last decade, however, that the process attained any degree of commercial success; but during the last few years it has given practically a new fibre to the textile industry.

Mercerizing, in its essential meaning, relates to the action of certain chemicals on cellulose, whereby the latter is changed to a product known as **cellulose hydrate**; though, technically, the term has come to mean the process concerned with the imparting of a silk-like lustre to the fibre. As generally understood, it consists briefly in impregnating cotton yarn or cloth with a rather concentrated cold solution of caustic soda and subsequently washing out the caustic liquor with water, the material being either held in a state of tension during the time it is treated with the caustic alkali in order to prevent contraction, or stretched back to its original length after treatment with the alkali, but previous to washing. In either case, the material must be in a state of tension during the process of washing. There are two separate phases of the mercerizing process represented in the above operations which must be separately understood in order

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to comprehend the exact nature of the change which takes place in the appearance of the fibre; the one is the chemical action of the caustic soda, and the other is the mechanical effect brought about by the tension. The action of the caustic alkali is to effect a chemical transformation in the substance of the fibre, a further chemical reaction taking place when this product is treated with water. As already pointed out (p. 219), cellulose has the property of combining with caustic soda to form a product known as **alkali-cellulose**, $C_{12}H_{20}O_{10}:NaOH$. The formation of this compound does not appear to disintegrate the organic structure of the fibre-cell, provided the proper conditions are maintained. The alkali-cellulose, however, is apparently a rather feebly combined molecular aggregate, and does not exhibit much stability towards reagents in general. It is even decomposed by the action of water, the effect of the latter being to disrupt the bond of molecular union between the alkali and cellulose, with the consequent re-formation of caustic soda and the introduction of water into the cellulose molecule. This latter substance, which may be termed cellulose hydrate, forms the chemical basis of mercerized cotton. The theory that caustic soda effects a true chemical combination with cellulose is somewhat supported by the fact that mercerized cotton undergoes chemical changes to which ordinary cotton is not susceptible. For instance, the former is much more readily dissolved by a solution of ammoniacal copper oxide; it is chemically reactive with carbon disulphide with the formation of soluble cellulose thiocarbonates; alkali-cellulose also reacts with benzoyl chloride and acetic anhydride, giving rise to cellulose benzoates and acetates. The nature of the chemical change in mercerized cotton, however, is rather ill defined; it no doubt can be included under that class of reactions which stands somewhat midway between ordinary physical and chemical changes, and is to be particularly observed in connection with those bodies possessing a high degree of molecular complexity, such as various colloidal substances and the large number of naturally occurring carbohydrates, starches, gums, etc. The fact that there is no evidence of disorganization in the fibre-cell, as may be observed from its physical properties and micro-

scopic appearance, is a strong argument against true chemical
change, which would necessitate a rearrangement in the atomic
grouping in the substance of the fibre. This would result in a
decomposition of its organized structure, which would at once
be manifested in a decrease in the tensile strength, and an actual
breaking down of the fibre itself. But mercerized cotton shows
no such change; on the other hand, its tensile strength is con-
siderably increased, and the fibre-cell shows no tendency towards
physical decomposition.

When the cotton fibre is immersed in a concentrated solution
of caustic soda it undergoes a peculiar physical modification; it
appears to absorb the alkali, swelling to a cylindrical form, so
that it presents more the appearance of a hair than a flat ribbon;
the fibre also untwists itself and becomes much straighter, at
the same time shrinking considerably in length. The internal
portion of the fibre acquires a gelatinous appearance, becom-
ing somewhat translucent to light, though it is firm in structure;
the surface of the fibre shows a wrinkled appearance transversely,
due to a somewhat unequal distension of the inner part. There
is a small degree of lustre on portions of the surface, but, due to
the uneven stretching and wrinkling of the external superficies,
the smooth lustrous portions are irregular in occurrence and not
very extensive in area. The fibre also shows a slight increase in
weight. These changes in the physical appearance of the fibre
are accompanied by a remarkable increase in the tensile strength,
amounting in most cases to as much as from 30 to 50 per cent.;
the fibre also acquiring a greater power of absorption towards many
solutions, most notably those of dyestuffs. The increase in tensile
strength is probably due to the fact that mercerizing causes the
inner structure of the fibre to become more solidly bound together
by a filling up of the interstitial spaces between the molecular
components of the cell-wall. In this manner the fibre as a whole
is given a greater degree of solidity; the internal strain between the
cell-elements (which must be quite considerable after the drying
out and shrinking of the ripened fibre) is lessened no doubt, and
hence adds to the unified strength of the fibre. From the fact
that the fibre shrinks in length in mercerizing, it is probable that

the cell-elements have contracted transversely on the collapse of the fibre canal, and, on being distended again by the action of the caustic alkali, these cell-elements become shortened longitudinally and are more tightly packed together. The increased affinity for dyestuffs exhibited by mercerized cotton is not to be considered a new inherent property of the modified cellulose induced by a change in its chemical composition. It is no doubt a result of the modified physical structure of the fibre itself; that is, when the cell-elements have become distended, like a sponge, they have a greater power of absorption and retention of liquids than when in a flattened and collapsed condition.

The high **lustre** imparted to cotton by mercerizing is brought about by other conditions than the mere action of the caustic alkali.* In the swelling of the cell-walls and consequent contraction of the fibre, the surface remains wrinkled and uneven, due to the unequal strain of expansion. If, however, the ends of the fibre are fixed, and thus prevented from contracting when subjected to the chemical action of the alkali, the swelling of the cell-walls will cause the surface to become smooth and even, and similar to a polished surface capable of reflecting light with but little scattering of the rays. Another condition which also has much to do with the production of the lustrous appearance is no doubt to be found in the physical modification of the cell elements themselves. When the fibre swells up under the action of the caustic alkali, its substance becomes gelatinous and translucent, and this has a marked effect on the optical properties of the fibre, and enhances the lustre considerably by lessening the proportion of light absorbed.†

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* It has been claimed that the mercerizing effect may be obtained without tension by the addition of glucose to the alkaline bath. The addition of other substances, such as ether, aluminium chloride, etc., have been claimed to produce the same result. But it is to be doubted whether a high lustre is obtained by any of these methods.

† Dr. Fränkel has advanced the opinion that the high lustre exhibited by mercerized cotton is mainly due to the fibre having lost its thin cuticle during the process. But this theory is overthrown by the fact that if mercerized cotton is again subjected to the action of cold strong caustic soda, it contracts nearly as much as raw cotton would do, and loses its silky lustre entirely.

Considerable difference is to be observed in the strength and elasticity of cotton mercerized without tension and that mercerized with tension. Buntrock, in a research on this subject, found that cotton yarn mercerized without tension showed an increase of 68 per cent. in its tensile strength,* whereas the same cotton mercerized under tension gave an increase of only 35 per cent. With respect to the elasticity of the yarn, the same chemist ascertained that the untreated cotton employed in his experiments stretched 11 per cent. of its length before breaking; the amount for cotton mercerized without tension was 17 per cent., an increase of 54 per cent.; cotton mercerized under tension showed no increase in elasticity at all, and could only be stretched the original 11 per cent. before breaking. These figures, of course, are not absolute for all varieties of cotton, but will vary within considerable limits, depending upon the character of the raw cotton employed. Attention must also be drawn to the fact that the figures for the tensile strength and elasticity quoted above were obtained by using spun yarn and are not based on the single fibre. Of course it is the strength of the yarn which is desired in practice, but the figure for this is not necessarily that for the fibre itself. In mercerizing yarn or cloth, it must be borne in mind that the fibres shrink considerably, and in doing so become more closely knit together; therefore the increase in tensile strength, as ascertained by Buntrock, represents really the greater coherence of the fibres to one another rather than an increase in the strength of the individual fibre, because in breaking a yarn spun from a large number of fibres there is little or no actual breaking of the fibres themselves, but only a pulling apart of the latter. The same criticism also applies to a determination of the elasticity. It would, perhaps, be more scientific to determine the breaking strain and elasticity of the separate fibres rather than that of the yarn or cloth; but it may be assumed, with considerable show

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* Grosheintz gives the following results of some experiments on the effect of mercerization on the tensile strength of cotton: Unmercerized yarn broke with a load of 356–360 grams; same yarn mercerized in cold aqueous caustic soda (35° Bé.) broke with 530–570 grams; same yarn mercerized with cold alcoholic caustic soda (10 per cent.) broke with 600–645 grams; same (except that hot alcoholic caustic soda was used) broke with a load of 690–740 grams.

of reason, that these figures of Buntrock will represent a fair relation between the strength and elasticity of the individual fibres. The cause of the lesser increase in tensile strength of cotton mercerized under tension as compared with that of the same cotton mercerized without tension is to be attributed to the fact that when the shrinkage of the fibre is prevented by the application of an external force the cell tissues cannot become as compact as otherwise, and there is also an internal strain induced which lessens the ultimate strength of the fibre. This latter condition also accounts for the lack of any increase in the elasticity of the mercerized fibre; the fibre when mercerized under tension is already in a stretched or strained condition, and can hardly be expected to give the same degree of elasticity as if tension had not been applied, as a certain part of its elasticity has been used up by the stretching.

2. **Conditions of Mercerizing.**—The proper conditions for carrying into practical operation the mercerizing process are simple and easily realized. Caustic soda is the most suitable and convenient reagent * for bringing about the hydration of the cellulose; and it has been found that a solution of density between 60° and 70° Tw. gives the best results. Caustic soda solutions of less density than 15° Tw. have scarcely any action on cotton; the maximum effect appears to be produced by a concentration of about 60° Tw., though the difference between this and that obtained at 50° Tw. is not very marked, and even at 40° Tw. the mercerizing action of the alkali is quite strong. Other reagents than caustic alkalies, however, may be employed for the hydrolysis of the cotton. Concentrated mineral acids, such, for instance, as sulphuric acid at a density of 100° to 125° Tw., will bring about the mercerizing effect more or less perfectly; the same is also true of certain metallic salts, most notably the chlorides of zinc, calcium, and tin. Beyond a mere theoretical and chemical interest, however, mercerizing by means of such

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* Solutions of caustic potash probably give a somewhat better lustre, and the shrinkage of the fibre is less than with caustic soda. But these small advantages are not sufficient to compensate for the extra expense which would be entailed by the use of caustic potash.

reagents has no practical value.* The addition of various chem-
icals, however, has been made to the caustic alkali solution with
beneficial results. It has been observed, for instance, that the
addition of zinc oxide has a very marked effect, and probably is of
considerable value in the practical working of the process. The
addition of glycerol, though perhaps of some benefit in assisting
in the even and thorough penetration of the liquor into the fibre,
can hardly be said to appreciably modify the general operation of
the alkali.† Previous treatment with Turkey-red oil is also of
benefit for the same reason; this is also true of such substances
as sodium silicate, sodium aluminate, and soap.

The temperature at which the reaction is carried out should
not be higher than the usual atmospheric degree; in fact, it has
been recommended to lower the temperature of the caustic soda
solution by the addition of ice, but this procedure does not appear
to add anything of material advantage. At elevated temperatures
caustic soda appears to exert a destructive effect on cotton, prob-
ably due to the formation of oxycellulose through hydrolysis and
subsequent oxidation. Beyond a certain temperature the mer-
cerizing effect rapidly diminishes, and at the boil it is scarcely
appreciable.‡ The best results appear to be obtained when the

* The use of sulphide of sodium or potassium instead of caustic alkali has
been proposed; but the process yields very uncertain results. It is claimed that
by adding ether to the caustic soda solution good mercerization can be obtained
with but little contraction of the fibre, but as this process requires fifty parts of
ether to twenty parts of caustic soda solution, the expense renders it ridiculously
impracticable. It is said that the addition of carbon bisulphide to the bath of
caustic soda very materially increases the lustre; this causes a disintegration of
the fibre, however, through the formation of viscose (see p. 230); hence the treat-
ment should be very brief, otherwise the cotton will be seriously tendered. The
mercerized fibre at first is as stiff as horse-hair, but this effect can be removed by
repeated washing. The sulphur can be removed from the cotton by washing in
a solution of sal-ammoniac, and this should be done before the material is treated
with an acid bath, as the latter would cause a precipitation of sulphur on the
fibre and so spoil the lustre.

† In the practical manipulation of the mercerizing process it has been found
that the impregnation with caustic liquor is greatly facilitated by the addition of
5 per cent. of alcohol on the weight of the caustic soda.

‡ Beltzer, however, claims that caustic soda solutions of 65° Tw. gave the
same results in mercerizing at 90° C. as at 15° C., but the cotton mercerized at
the higher temperature was much more transparent than the other. The lustre,

.emperature is maintained at 20° C. or lower. Above this point the contraction of the fibre (which may be taken as a measure of the degree of mercerization) grows less and less with rise of temperature.

The mercerizing action of caustic soda is rather a rapid one, as it requires only a few minutes for its completion; in fact, it appears to take place simultaneously with the impregnation of the fibre by the liquid. In ten minutes mercerization is practically complete, and lengthening of the time does not increase the mercerizing effect; in fact, too long a contact of the cotton with the caustic alkali is to be avoided, especially if the impregnated fibre is exposed to the air, as there is danger of a breaking down of the cellular structure and a consequent deterioration in the strength of the fibre. The time of immersion also appears to be independent of both the temperature and the concentration of the alkali.

There are two ways in which the tension may be applied in mercerizing: (*a*) The material may be held in a state of tension during the time of its treatment with the caustic alkali, and until the alkali has been washed out, in which case the tension should be so maintained that the material cannot shrink; (*b*) the tension may be applied after the material has been treated with the caustic alkali, but before the latter is washed out, in which case sufficient tension should be exerted to stretch the material back to its original length. If the tension is not applied until after the alkali has been removed from the fibre, no lustring effect is produced; it is absolutely essential that the stretching should take place while the fibre is in the form of an alkali-cellulose, and before it has been converted by treatment with water into hydrated cellulose.

According to the experiments of Herbig, the stretching force necessary to keep the cotton in its original length during mercerization is only from a quarter to a third of that necessary to do the stretching after mercerization; but there appears to be no

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however, was in no wise inferior. If the mercerization be conducted at 90° C., it is necessary to keep the cotton entirely immersed, to guard it from contact with the air, otherwise it will become seriously weakened.

appreciable difference in the lustre obtained. It would appear, however, that stretching beyond a certain point ceases to increase the lustre, and to obtain the maximum lustring effect it is not necessary to stretch the cotton back to its original length. Herbig concluded that stretching during mercerization is disadvantageous, and it is best to mercerize the yarn loose, wring it, and only stretch while rinsing, as the required stretching force is then quite small. The best time for stretching, then, is during the conversion of the soda-cellulose into the hydrocellulose. If the stretching does not take place until after rinsing, almost twice the force is necessary to restore the yarn to its original length, as when in contact with the lye, and the lustre is decidedly inferior. The stretching force also appears to depend on the twist, being greater in proportion as the twist is harder.*

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* Herbig gives a summary of his experimental results as follows:

1. Loose yarn mercerized without any stretching, whether long- or short-stapled, and whether with or without a hard twist, has less lustre than unmercerized yarn. But even with a very slight tension the lustre is greater.

2. Both with long- and short-stapled cotton the lustre only becomes marked when the stretching force is sufficient to bring the yarn back to its original length.

3. Stretching beyond the original length does not give any increase in lustre.

4. Considerable difference is observable in the stretching force needed between loose mercerization followed by stretching in the lye, and keeping the cotton at its original length during mercerization, as in the latter case only one-third to one-quarter of the force is necessary to produce the silky lustre.

5. The stretching of the yarn requires only a small force when mercerized loose and if applied when rinsing is actually in progress; for the best time for stretching is during the conversion of the soda-cellulose into hydrocellulose.

6. When rinsing is over, twice as much force is needed to restore the original length as is required for yarn still in contact with the lye; and yarns so treated contract somewhat on drying, and exhibit an inferior lustre.

7. The stretching force necessary in mercerizing yarn varies with the twist, and in general is greater in proportion as the twist is harder.

8. The production of the silky lustre does not depend primarily on the amount of force employed in stretching, as soft yarn with only a small amount of twist can be lustred.

9. The production of the silky lustre is independent of the cotton being long- or short-stapled, as short-stapled American cotton with even a loose twist can be given a silky lustre.

10. The production of a high degree of lustre depends to a considerable extent on the fineness of the fibre and its natural lustre. This is apparent in mercerizing sea-island and Egyptian cotton.

By the washing of the material after steeping in caustic alkali, a twofold object is gained. In the first place, the action of the water on the alkali-cellulose is to effect a chemical transformation into cellulose hydrate, and this action is as really essential to mercerizing as the action of the caustic soda itself. In the second place, the washing is conducted for the purpose of removing all excess of caustic alkali from the material.* Caustic soda is held quite tenaciously by cotton, and it requires a very thorough and long-continued washing to remove the last traces of this compound. In order to shorten the period required for washing, it is customary to give the cotton first a rinsing in fresh water, after which the tension may be relieved, and then to wash with acidulated water, using acetic acid for this purpose.† On drying the material without further washing, it will be found that the acetic acid has imparted to the cotton a certain degree of " scroop," somewhat after the nature of silk, without in any manner tendering the fibre. If other acids, and especially mineral acids, are employed for washing, a subsequent rinsing with fresh water and soaping is necessary for the purpose of neutralizing all of the acid, which would otherwise seriously tender the goods on drying, unless the amount of acid employed is so accurately adjusted as not to leave any free acid in the fibre.

The character of the fibre employed has a considerable influence on the success of the mercerizing process. From the very nature of the fact that a considerable degree of tension must be applied to the fibre during the process in order to obtain the desired lustre, it would be natural to expect that the longer the staple of the fibre the more readily would it lend itself to the requirements of the operation. And such, indeed, is found to be the case; the long-stapled sea-island ‡ and Egyptian varieties

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* When mercerized cotton is rinsed with ammonia instead of water it retains its gelatinous, parchment-like consistency throughout the rinsing, and can be stretched to its original length without breaking. If the cotton is then rinsed with water while still stretched, the fibre regains its original appearance and acquires a lustre as good as that obtained in the usual way.

† Sulphuric acid is also much used in the washing. The acid employed is of ½° Bé. strength, and at a temperature of 50° C.

‡ The preparation by combing of cotton for mercerization has a considerable

of cotton are those especially adapted for use in the preparation of mercerized cotton, while the shorter-stapled varieties are but little employed for this purpose, as the lustre obtained with them is by no means as pronounced.* The quality of being mercerized, however, is not an inherent property of any special variety of cotton, as was formerly supposed to be the case; any variety of cotton is capable of mercerization, the only essential being that the fibre shall be maintained in a state of tension. In order that this condition be realized with short-stapled fibres, the yarn operated upon must be tightly twisted in order to present sufficient cohesion among the individual fibres to allow of the high tension required; this, on the other hand, prevents an even and thorough penetration of the caustic alkali into the substance of the fibre, so that, on the whole, the results obtained with short-stapled fibres are not at all comparable with the long-stapled varieties.† By later improvements in the manner of applying

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influence on the subsequent lustre of the yarn. Sea-island cotton possesses a rather silky fibre to begin with, and this is made more adaptable to the production of a high lustre by combing, in which operation the fibres are arranged parallel, and still further by gassing, which burns off the minute outer hairs. Yarns possessing considerable lustre were made in this manner with fine counts of sea-island cotton long before the discovery of lustring by mercerization, and it was always recognized that the parallelism of the fibres so obtained by combing (and sometimes a second combing) was a great factor in the production of a silky and lustrous yarn.

* Fabrics of vegetable fibres (cotton or linen) may also be mercerized in patterns by printing on certain compounds capable of resisting the action of the caustic soda in the subsequent mercerizing process. Resists suitable for this purpose are, in the first place, organic compounds which readily coagulate, such as albumin and casein; and secondly, such salts, acids, or oxides which may act by neutralizing the caustic alkali, or from which a hydrate may be precipitated on the fabric by its action. Such compounds, for instance, as the salts of aluminium or zinc, organic acids, and the oxides of zinc, aluminium, or chromium are quite suitable. Very beautiful effects are said to be obtainable by this process.

† Boucart gives the following reasons why only long-stapled cotton, and that only in particular counts, gives good results on mercerization. A simple thread consists of a sort of twisted wick composed of nearly parallel fibres. The twist depends, as regards the angles it makes with the length of the thread, both upon the kind of cotton and upon the count of the yarn. Of the two sorts of simple yarns, warp-yarns have more cohesion among their elements than tensile strength, while the reverse is the case with weft-yarns. The result is that under gradually

the tension, however, it would seem that, by realizing the proper mechanical conditions, even cotton of comparatively short staple will be capable of being mercerized in a more successful manner than heretofore.*

3. Properties of Mercerized Cotton.—Outside of its high lustre and somewhat increased tensile strength, mercerized cotton exhibits but few apparent differences from the ordinary fibre.

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increasing tension weft-fibres slide past one another without breaking, but warp-fibres break before any such occurrence takes place. The degree of twist also depends on the mean staple, and the angle between the thread and the axis at any point is proportional to the length of the thread. The degree of twist which is required to make the cohesion exceed the tensile strength depends naturally on the strength of the fibre. The mercerizing process tends to shorten each individual fibre, and this shortening is resisted by tension in the direction parallel to the axis of the thread. Hence the greater the angle the thread makes with that axis the less is the effect of the tension, and if any portion of the fibre is at right angles to the axis it is not affected by the tension at all. Hence a simple warp-thread can only receive a medium amount of gloss from mercerization, and the less the greater the twist. Slightly twisted threads must give the best lustre, but if the cohesion of the fibres is less than the contractile force exerted by the lye, the fibres slip past each other and no lustre is produced. But if the weft-threads are fixed, as in piece goods, they take a better lustre than the warp, although the latter is usually made of better cotton. Short-stapled cotton lustres badly because it must be more tightly twisted. The best lustre of all is obtained with twofold twist, in which the outer fibres lie parallel to the axis, and the yarn should be well singed to remove projecting fibres.

* The process of mercerizing has been subject of late to a great number of patents, especially by Thomas and Prevost of Germany. This has resulted in considerable litigation in many countries. As far as the actual chemical process itself is concerned, however, there does not appear to have been any material advance beyond the facts first discovered by Mercer and patented by him in 1850; with regard to the element of carrying out the process under tension, it may be said that this was first described and patented by Arthur Lowe in 1890, and this included the application of tension either during or after the treatment with caustic alkali. Lowe's object in stretching the material, however, was primarily to prevent the loss encountered by the shrinkage of the goods, though he does also make a specific statement that the cotton acquires an increased lustre and finish by the process. The only novelty put forward by Thomas and Prevost was the use of a particular kind of cotton, that is, long-stapled varieties; but as both Mercer's and Lowe's patents claim the use of all varieties of cotton, it is difficult to see on what ground Thomas and Prevost can substantiate their claim for a patent. Patents covering the process of mercerizing appear to be without foundation; though for machinery and appliances for carrying out the same such patents may be perfectly legitimate. Recent decisions on this matter in the United States have invalidated Thomas and Prevost's patents in this country.

Towards dyestuffs and mordants it is rather more reactive, and consequently will dye deeper shades with the same amount of dyestuff than ordinary cotton; this property is rather to be ascribed to the increased absorptivity of the fibre than as the result of any chemical modification of the cellulose composing it; it is also
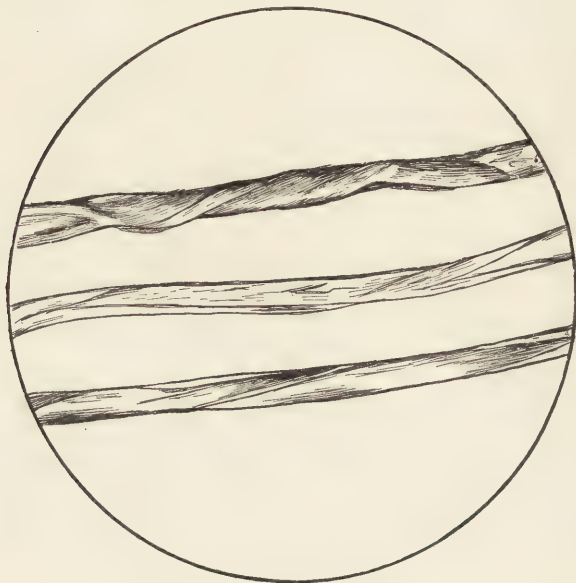
FIG. 62.—Mercerized Cotton.   (×350.)   (Micrograph by author.)

independent of the method of mercerizing, that is, whether accompanied by tension or not.

Microscopically the mercerized cotton fibre exhibits a considerable difference from that of ordinary cotton. Whereas the latter, when viewed under the microscope, appears as a twisted flat band with thickened edges, and in cross-section like a collapsed tube, mercerized cotton appears as a rather smooth cylindrical fibre, the cross-section of which is more or less circular. It rarely happens that a fibre absolutely loses all of its twist, though the degree of mercerization may be measured by the freedom of the fibre from irregularities and twists. Under ordinary conditions when the cotton is mercerized in a state of tension, it will

also be found that many fibres will remain in their original form, or unmercerized, whereas others will be mercerized only in portions of their length. The microscopical examination of mercerized cotton is important in determining just how perfectly the process has been carried out, which may be judged by the relative number of unmercerized or partially mercerized fibres which may be present.

Cotton may be mercerized either in the form of yarn or of cloth, and it is principally done in the unbleached condition. There has been some dispute as to which is best: to mercerize first and bleach, or to bleach first and then mercerize; experience, however, appears to favor the first method. In the bleaching operations, which usually involve a rather severe treatment of the cotton first with moderately strong alkalies and subsequently with solutions of bleaching powder, the fibre suffers more or less chemical alteration, so that in the mercerizing process it can no longer enter into proper chemical union with the caustic soda employed; and hence complete true mercerization is not effected. Although cotton should be thoroughly scoured (" boiled out ") before being mercerized, it is best not to use alkalies for the purpose, but to employ Turkey-red oil (or other suitable sulphated oil) or soap. If bleaching is carefully conducted after mercerizing, the injury to the lustre of the fibre is very slight. Mercerized cotton does not require a prolonged boiling in alkalies previous to the operation of bleaching as with ordinary cotton. To obtain the best conditions for high lustre, yarn should be well " gassed " (singed) before mercerizing, as otherwise the external, hairy fibres remain loose and cannot be subjected to tension. As a result, these fibres shrink, and, remaining without lustre themselves, hide to a certain extent the lustred surface of the yarn. Moreover, caustic soda has a felting action on these free filaments, and felting is especially harmful to lustre.

In mercerizing cloth the action taking place between the sizing materials (always present to a greater or lesser degree in cotton cloth) and the caustic alkali is sufficient at times to raise the temperature considerably, which may result in a deficient lustre. In such cases recourse must be had to artificial cooling

by addition of ice or a current of cold water in order to prevent
an undue rise in temperature.

When mercerized cotton is to be bleached, it is best, after the
first rinsing, to remove the major portion of the caustic soda and
arrest the mercerization, not to rinse again in acidulated water, as
would ordinarily be done if the material were not to be immedi-
ately bleached. The small amount of caustic soda which still
remains in the cotton acts in a beneficial manner in bleaching.

A silky lustre resembling that produced by mercerization can
be given to cotton cloth by means of what is known as a calender
finish. This is accomplished by passing the cloth between rollers
under heavy pressure, one of the rollers being engraved with
obliquely set lines ruled from 125 to 600 to the inch. The effect
is to produce a great number of parallel, flat surfaces on the cloth,
which causes it to acquire a high lustre. By conducting the opera-
tion with hot rollers quite a permanent finish can be produced
which closely approximates mercerized cotton. Cloth so fin-
ished, however, loses its lustre in a large degree on washing.
The method is chiefly known as the "Schreiner process."

CHAPTER XIII.

SEED-HAIRS OTHER THAN COTTON.

1. Bombax Cotton.—Besides the cotton derived from the ordinary species of the cotton plant (*Gossypium* family), there is a very similar seed-hair fibre obtained from a plant known as the *cotton-tree* and belonging to the *Bombaceæ* family. The fibre is known in trade as *vegetable down* or *bombax cotton*. It grows almost exclusively in tropical countries. The fibre is soft, but rather weak as compared with ordinary cotton; in color it varies from white to a yellowish brown, and it is quite lustrous. The fibres have a length of from 10 to 30 mm., and a diameter of from 0.020 to 0.045 mm. Owing to its weakness and lack of elasticity, bombax cotton is not used by itself as a textile fibre; it is sometimes mixed with ordinary cotton and spun into yarn, but it is principally used as a wadding and upholstery material.

In its physical appearance, bombax cotton differs from true cotton in not possessing any spiral twist and showing irregular thickenings of the cell-wall; the fibre usually consists of one cell, though occasionally it may have two. Unlike true cotton, the fibre does not grow directly from the seed, but originates at the inner side of the seed-capsule.

There are several varieties of plants from which vegetable down may be obtained. In Brazil it is obtained from the *Bombax heptaphyllum* and *B. ceiba*, and the product is known as *Paina limpa* or *ceiba cotton*. This is also produced in the West Indies and other parts of tropical America. In *Bombax ceiba* the fibre has a length of from 1 to 1.5 cm., while in *B. heptaphyllum* the fibre length is from 2 to 3 cm., being by far the longest and strongest variety of bombax cotton. *B. malabaricum*, of South

Asia and Africa, has fibres from 1 to 2 cm. in length; this latter is known in India as *Simal* cotton or red silk-cotton. Other varieties of *Bombax* plants are *B. cumanensis* of Venezuela, giving a product known as "*lana del tambor*" or "*lana vejetale*"; *B. pubescens* and *B. villosum* from Brazil; *B. carolinum* from South America; *B. rhodognaphalon* of West Africa, the fibre of
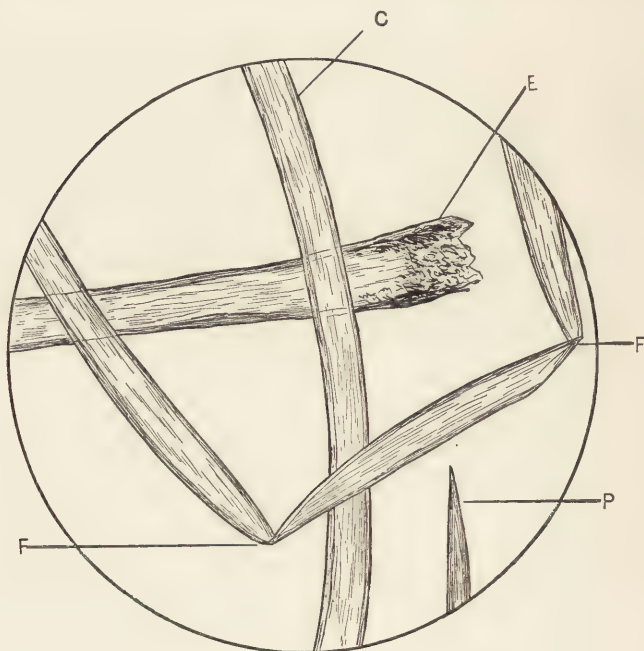
FIG. 63.—Vegetable Down.   (×350.)

E, lace-like structure at base; *F*, fibre folded on itself; *P*, point of fibre; *C*, thin cell-wall.   (Micrograph by author.)

which is known as wild kapok and is used largely for the stuffing of pillows.

The microscopical characteristics of vegetable down are as follows: The fibre consists of a single cell, possessing a cylindrical shape, being rather thick at the base and tapering gradually to the point.   The base of the fibre is frequently swollen and exhibits a lace-like structure (see Fig. 63).   The cell-wall is usually very thin, occupying not more than one-tenth the width of the

fibre. The cross-section is circular and not flat, as in the case of cotton. The inner canal is partly filled with a dried-up proto-plasmic membrane.

In its chemical constitution vegetable down differs from ordinary cotton in containing a certain amount of lignified tissue; consequently it furnishes a yellow coloration when treated with anilin sulphate or with iodin and sulphuric acid, and by these tests it may readily be distinguished from true cotton. Owing to its lignified nature the fibres also swell but slightly when treated with Schweitzer's reagent. The fibre from the *Bombax ceiba* is distinguished by its decidedly yellowish color.

The seed-hairs of the *Eriodendron anfractuosum* (or *Bombax pentandrum*) are very similar to the preceding varieties of vege-table down. It gives the product known in Holland as *kapok*. In both their physical appearance and chemical properties it is almost impossible to distinguish between kapok and *ceiba* cotton. Kapok is obtained from South Asia and the East Indies, and is very extensively used as upholstery material, and also for the stuffing of life-saving belts on account of its low specific gravity.

The hair-fibres of the *Ochroma lagopus* (from the West Indies) have a length of from 0.5 to 1.5 cm., and are thicker in the middle than at the ends. The cell-wall is much thicker than with bombax cotton, and the fibres are also more highly lignified than those of the latter. They occur in trade as *édrédon végétale* or *pattes de lièvre*, and the product comes mostly from Guade-loupe and Martinique. The *Ouate végétale* of the French trade is a mixture of fibres from *Bombax*, *Ochroma*, and *Chorisia* varieties.

The *Cochlospermum gossypium* of India and the *Chorisia speciosa* and *C. insignis* of South America also furnish fair quali-ties of vegetable down.

Pulu fibre can also be classed under the general name of vegetable down. It is the hair obtained from the stems of fern-trees, more especially the *Cibotium glaucum* of the Hawaiian Islands. The fibres are lustrous, of a golden brown color, very soft, and not especially strong. They have a length of about 5 cms., and are composed of a series of very flat cells, pressed

together in a ribbon-like form. The fibre is only employed as an upholstery material and is never spun. Similar fibres are also obtained from *Cibotium barometz*, *C. menziesii*, and *C. chamissoi;* the second one produces the best fibre.

2. **Vegetable Silk.**—Another seed-hair which is utilized to some extent as a fibre is the so-called vegetable silk or *Asclepias cotton*.

This fibre is obtained from *Asclepias syriaca* and *A. incarnata* or common milkweed or silkweed. The plant grows extensively in America. The surface fibre from the seed-pods * is used for upholstery material; it has also been used in France for the manufacture of woven fabrics, being spun with 80 per cent. of wool, and made into a fabric known as "silver cloth."

The fibre of vegetable silk is quite brittle in nature and possesses but little tensile strength; hence attempts at spinning it by itself have not proved very successful. Its chief physical quality is its high degree of lustre and softness. When examined under the microscope, the fibre exhibits thickened ridges in the cell-wall which serve to distinguish it from *Bombax* cotton. Each fibre consists of a single cell, usually somewhat distended at the base. It is of a yellowish white color; the length varies from 10 to 30 mm. and the diameter from 0.02 to 0.05 mm. As vegetable silk is somewhat lignified, it may be distinguished from true cotton by giving a yellowish brown coloration with iodin and sulphuric acid, and a yellow coloration with anilin sulphate. Its micro-chemical reactions are very similar to *Bombax* cotton, though with phloroglucol and hydrochloric acid the latter gives a dull violet coloration, while vegetable silk gives a bright red-violet coloration.

There are several minor varieties of vegetable silk, chief among which are the following: *Asclepias curassavica* and *A. volubilis* from the West Indies and South America; *Calotropis gigantea* and *C. procera* of southern Asia and Africa; several species of *Marsdenia* from India; *Beaumontia grandiflora* from India, and different varieties of *Strophantus* from Senegal.

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* The same plant also furnishes a bast fibre which is fine, long, and glossy and said to be equal in strength and durability to hemp.

The different varieties of vegetable silk are very difficult to distinguish from one another. They all possess a soft feel and a high silky lustre. In color they vary from almost pure white to a slight orange-yellow. In thickness the fibres usually vary from 35 to 60 μ, though occasionally they may reach 80 μ. In length they vary from 10 to 50 mm. The fibre has but little pliability or elasticity, hence is very brittle; this is due to the very thin cell-wall. All varieties exhibit the thickened ridge in the cell-wall, which gives the fibre the appearance of being uneven in thickness. In cross-section, these ridges are usually semi-circular, though sometimes flat and broad. The cross-section of the fibre itself is usually circular.

The seed-hairs of the *Beaumontia grandiflora* furnishes probably the best variety of vegetable silk, as the fibre is not only the most lustrous but is also the most purely white, while it also possesses the greatest tensile strength and the fibres are easily separated from the seeds. The fibres are from 3 to 4.5 cm. in length and from 33 to 50 μ in diameter. The thickness of the cell-wall is about 3.9 μ. At the base the fibre is somewhat enlarged. The fibre of *Calotropis gigantea* * is from 2 to 3 cm. in length and from 12 to 42 μ in diameter; the cell-wall is from 1.4 to 4.2 μ in thickness. At the base the fibre is somewhat enlarged and

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* *Calotropis gigantea*, or giant asclepias, also yields a bast fibre said to be of very superior quality, somewhat resembling flax in appearance and of the same strength. The vegetable silk enveloping the seeds is known in India as madar floss. The bast fibre is said to show a high degree of resistance to moisture; according to Spon, samples exposed for two hours to steam at two atmospheres pressure, boiled in water for three hours, and again steamed for four hours, lost only 5.47 per cent. in weight, whereas flax under the same conditions lost 3.50 per cent., manila hemp 6.07 per cent., hemp 6.18 to 8.44 per cent., and coir 8.14 per cent. As to the strength of the fibre, Dr. Wright's tests give it a breaking strain of 552 pounds as compared with 404 pounds for sunn hemp; Royle's tests give it a breaking strain of 190 pounds as compared with 160 pounds for Russian hemp and 190 pounds for Jubbulpore hemp from *Crotalaria tenuifolia*. The vegetable silk from *Calotropis gigantea* is known in Java under the name of kapok, though this name is also given to the product of the *Eriodendron anfractuosum* and *Bombax pentandrum*. The fibre is said to have been made into shawls and handkerchiefs, but it hardly possesses sufficient strength to be spun alone. The *C. gigantea* is not only a fibre plant, as it also yields gutta-percha, varnish, dye, and medicinal substances.

flattened, though this formation is not so perceptible as in the case of *Beaumontia grandiflora*. The fibre of *Calotropis gigantea* is known in Venezuela as *algodon de seda*. The fibres from the various species of *Marsdenia* are very uniformly cylindrical and straight. In length they vary from 1 to 2.5 cm. and in diameter from 19 to 33 μ. The cell wall has an average thickness of 2.5 μ. The fibre of *Strophantus* differs somewhat from other varieties, in that at the base there occur pores in the cell-walls. This fibre is also not so easily removed from the seeds and possesses a reddish yellow color.

Vegetable wool is a product obtained from the green cones of the pine and fir by processes of fermentation, washing, and mechanical disintegration. It is used in mixtures with cotton and wool for the production of yarns, and also for the stuffing of mattresses, etc. The yarns prepared from vegetable wool mixed with sheep's wool are used in the manufacture of the so-called "hygienic flannels." *

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* These are especially recommended for gouty patients, as it is claimed they keep the body uniformly warm and protect it from dampness.

CHAPTER XIV.

ARTIFICIAL SILKS; LUSTRA-CELLULOSE.

1. General Considerations.—Owing to the high price and value of silk as a textile fibre, numerous attempts have been made to produce an artificial filament resembling it in properties.* Several of these processes have been attended with a considerable degree of success, and at the present time artificial silk has become a commercial article, and is used in considerable quantity by the textile trade.† The varieties of these silks divide themselves into the following classes:

(1) Pyroxylin silks, made from a solution of guncotton in a mixture of alcohol and ether.

(2) Fibres made from a solution of cellulose in ammoniacal copper oxide or chloride of zinc.

(3) Viscose silk, made from a solution of cellulose thiocarbonate.

(4) Gelatin silk, made from filaments of gelatin rendered insoluble by treatment with formaldehyde.

With the exception of the last class, all of these so-called silks are filaments of cellulose, resolidified from various kinds of solu-

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* The entomologist Reaumur, in the year 1734, in a memoir on the history of insects, appears to have been the first to look forward to the possible preparation of silk by artificial means. It was not until 1884, however, that the first commercial process for the preparation of artificial silk was taken out in patent form by the Count Hilaire de Chardonnet.

† The first attempt at the spinning of a solution of collodion appears to have been made by Audemars at Lausanne (Eng. Pat. 283 of 1855). Further experiments were made by Weston (Eng. Pat. of Sept. 12, 1882) and Swan (Ger. Pat. 30291 of 1884) on solutions of nitrated cellulose in acetic acid. Wynne-Powell (Eng. Pat. of Dec. 22, 1884) tried the preparation of filaments from a solution of cellulose in zinc chloride. All of these attempts had in view the preparation of filaments for incandescent electric lamps.

tions, hence it has been proposed to give to these fibres the general name of **lustra-cellulose**, as one more descriptive of their true nature.*

The large majority of the lustra-cellulose used in trade at the present time falls under the first class of pyroxylin silks. This represents the oldest and most successful method employed for the manufacture of this interesting fibre; and there are three chief processes by which the silk is made, known by the names of the respective inventors: Chardonnet, du Vivier, and Lehner. All of these processes use a solution of nitrated cellulose as a base, and employ the same general mechanical idea to produce the filaments of the fibre, the principle being to force a solution of nitrated cellulose through a fine capillary tube, coagulate the thin stream of solution thus obtained, and finally denitrate and reel the thread of filaments so obtained. As previously described (page 225), cellulose, on treatment with nitric acid, can be made to yield a series of nitrated celluloses, the exact compound obtained being dependent upon the conditions of treatment.

2. Chardonnet Silk.—This is prepared from octonitrated cellulose dissolved in a mixture of alcohol and ether.† The

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* From the term "artifiicial silk," many would reasonably suppose that the substance so designated is the same in composition and nature as the fibre derived from the silkworm, but made by chemical or other artificial means. This is not the case, however, and the term "artificial silk" is rather a misleading one in this sense. The name in reality stands for a fibre resembling in its lustre and general appearance the true silk of nature; but the identity goes no further than this; for, in its chemical composition and properties, artificial silk is entirely distinct from that produced by the silkworm. It would be better to call the artificial product "imitation silk," or give it some name more distinctive of its origin and true nature, such as the term "lustra-cellulose," proposed by Cross and Bevan. The latter term is especially adapted to the product in question, for the different varieties of this fibre which have acquired any degree of technical importance are all made from cellulose derivatives, and their chief quality is their high degree of lustre.

† Many attempts have been made to reduce the cost of the collodion and to obtain other solvents for the nitrated cellulose. Bronnert in 1895 brought forward a process of making collodion, based on the solubility of tetranitrated-cellulose in alcoholic solutions of certain salts, such as calcium chloride, ammonium acetate, and ammonium sulphocyanide. The explanations advanced for these reactions are rather uncertain. It may be supposed that the ammonium acetate produces a hydrolysis, the ammonium sulphocyanide a partial denitration of the

solution is coagulated by passage through water, and is subsequently denitrated * by a treatment with dilute nitric acid, chloride of iron, and ammonium phosphate. It forms a glossy, flexible fibre, possessing the peculiar feel and scroop of true silk.

The pyroxylin employed for the production of Chardonnet's silk may be prepared from either wood-pulp, cotton, ramie, or
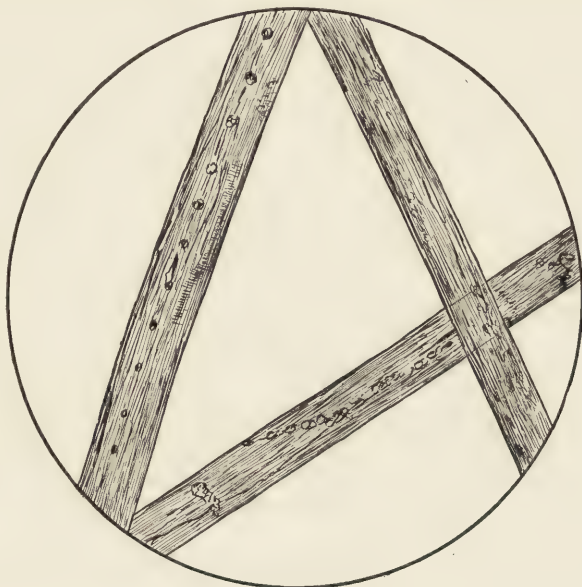
Fig. 64.—Chardonnet Silk. (×350.)
(Micrograph by author.)

other source of purified cellulose. As there are several nitrated compounds of cellulose soluble in the alcohol-ether mixture

tetranitrated-cellulose, and the calcium chloride an alcoholic derivative of the cellulose, which could well be an ethoxy-derivative, if the opinion of Dr. Bronnert, "that the body designated by the name of tetranitrated-cellulose is a tetranitrated-oxycellulose," is correct. The different compounds thus formed would be soluble in alcohol. (See Bernard, *Mon. Scientif.*, May, 1905.)

* When first prepared, pyroxylin silks were very inflammable, which led to their being regarded with disfavor. The processes of denitration, however, have now rendered them even less inflammable than ordinary cotton. *Antiphlogin* is the trade-name of a mixture used for the purpose of overcoming the inflammable nature of artificial silk. It consists of boric acid, phosphate of ammonia, and acetic acid. Pyroxylin steeped in this solution is said to be incombustible.

(which is employed as the pyroxylin solvent), and as it is difficult to obtain satisfactory separations of the individual compounds, it is probable that the pyroxylin contains penta-, tetra-, tri-, and di-nitrated cellulose, the tetra- and tri-nitrated compounds probably occurring in larger amounts. The preparation of a pyroxylin, suitable for use in the making of Chardonnet silk, as prescribed by Wyss-Naef, calls for a nitrating mixture of 15 parts of fuming nitric acid (sp. gr. 1.52), with 85 parts of commercial sulphuric acid. For 4 kilograms of cellulose about 35 litres of this acid mixture are required, and the time of action is from four to six hours. Samples are examined from time to time with the micro-polariscope in order to ascertain the degree of nitration, and when all the fibres appear of a uniform bright blue color under the polariscope the action of the acid mixture is discontinued. The excess of acid is removed from the fibre by means of a hydraulic press, after which the nitrated cellulose is washed for several hours with water and then pressed again, until the mass contains only about 30 per cent. of water. At first the pyroxylin so prepared was dried before being dissolved in the alcohol-ether solvent, but it was subsequently discovered that a better solution could be obtained by using the pyroxylin containing the amount of water above noted. This form of pyroxylin has been called by Chardonnet " pyroxylin hydrate," but it is doubtful if the substance is a true hydrate. However, it appears to be about 25 per cent. more soluble than the dry pyroxylin. The solvent employed for the pyroxylin consists of a mixture of 40 parts of 95 per cent. alcohol with 60 parts of ether, and 100 parts of this liquid will dissolve about 28 to 30 parts of pyroxylin. The collodion so produced is filtered several times under pressure, in order to free it from all non-nitrated and undissolved fibres, and to obtain a perfectly clear and homogeneous solution. This condition is a very essential one for the successful production of the silk, as any irregularity in the solution would cause a break in the continuity of the spun filament or a stoppage of the machine. The pyroxylin requires from 15 to 20 hours for complete solution, and that prepared from cotton requires a longer time to dissolve than that from wood-pulp. In order

to properly filter the solution a pressure of 30 to 60 atmospheres is necessary.

The next operation in the manufacture of the silk is purely a mechanical one, and yet one which has required the use of considerable ingenuity and skill.* The object is to force the collodion solution through very fine capillary glass tubes, so that it may be drawn thence as a fine continuous filament. The collodion solution is quite viscous, and requires a pressure of from 40 to 50 atmospheres to force it through capillaries of 0.08 mm. diameter. The flow of solution and pressure must be so adjusted and capable of regulation as to provide a uniform filament, and this involved many mechanical difficulties, which were only overcome after long experimenting and numerous failures. We will not, however, at this point enter into a consideration of the various mechanical devices, ingenious though they are, which

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* An outline of the methods employed in the practical manufacture of Chardonnet silk is as follows: A good quality of wood-pulp is carefully disintegrated by suitable machines (resembling a carding-machine), so as to separate the individual fibres as much as possible. The bulky, fleece-like mass is then dried by steam heat at 140°–160° C., after which the heated fibres are steeped in a mixture of concentrated sulphuric and nitric acids, as in the general method of making gun-cotton. After suitable treatment in the acids, the nitrated cotton is centrifugated to remove excess of acid, then washed until it contains only about 10 per cent. of acid. The product was formerly dried in special drying-rooms, where the temperature should not be above 30° C., and every precaution must be taken to avoid explosions. The dried nitrated cellulose was then dissolved in a mixture of equal parts of alcohol and ether, so as to secure a 20 per cent. solution. The resulting collodion (as the solution is now known) is carefully filtered through silk sieves in such a manner as to remove all undissolved fibres or other foreign matter. The collodion then passes to the spinning-machine where it is forced through tubes having nozzles of glass or platinum with fine orifices. As the threads of collodion appear they come into immediate contact with a fine stream of water, which removes the solvent and coagulates the cellulose compound. Several of the fine threads are united and are wound on bobbins and into suitable hanks. The silk is then denitrated by treatment with a warm solution of ammonium sulphide, after which the hanks are washed and slightly acidified in order to remove all the ammonium compounds. The process of denitration causes the silk to lose about 40 per cent. in weight, though this is usually replaced in part by proper impregnation with solutions of metallic salts, which also have the effect of making the silk fire-proof. In the manufacture of collodion silk, an important factor is the recovery of the solvent from the wash-waters; owing to the extreme volatility of the ether this is by no means an easy task.

have been perfected for the proper spinning and handling of this artificial fibre.*

The thread as it emerges from the capillary tube is rapidly coagulated in the air by the evaporation of the solvent. By suitable arrangement of a hood over the machine and condensing chambers in connection therewith, a large portion of the mixed volatile vapors of the alcohol and ether employed as the solvent are condensed and collected, thus effecting a considerable saving in the amount of solvent required, and also minimizing the danger of explosions occurring. Several of the individual filaments are brought together into a single thread and wound on spools in the manner of ordinary silk. In this operation a certain amount of adhesion takes place between the separate filaments, which considerably enhances the ultimate strength of the finished thread. The thread in this form now consists of pyroxylin or nitrated cellulose, and is highly inflammable and otherwise unsuitable for use in textile fibres. The next operation through which it passes is one for the purpose of denitrating the cellulose, in order that the fibre may ultimately consist of what might be termed " regenerated " cellulose, the exact chemical nature of which it is not possible to definitely state, though it is evidently some form of cellulose. The denitration is accomplished by passing the pyroxylin threads through a bath of ammonium sulphide, though other alkaline sulphides, and various other compounds also, will effect the same result. The silk in this condition has a rather yellow color, which, however, may be bleached out in the usual manner with a solution of chloride of lime. The fibre, as finally obtained, possesses a very high lustre, though it is somewhat metallic in appearance; it has considerable tensile strength, though in this respect, as also in elasticity, it is considerably below true silk. The fibre is also rather harsh and brittle, and does not possess the softness and resiliency of natural silk.†

3. **Du Vivier's Silk.**—The basis of du Vivier's silk is a solution of trinitrated cellulose in glacial acetic acid. In practice,

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* See Sìlvern, *Die kunstliche Seide*, Berlin, 1900, and Williams, *La Soie Arti ficielle*, Paris, 1902.

† See Matthews, *Jour. Soc. Chem. Ind.*, 1904, p. 176.

this is mixed with a solution of gutta-percha in carbon disulphide, and one of isinglass in glacial acetic acid. Small quantities of glycerol and castor-oil are added, and the mixture is drawn through the spinning-tubes into water, where it becomes coagulated. The thread which is so formed is treated successively with soda, albumin, mercuric chloride, and carbon dioxide. Du Vivier's silk is hard, and very white and glossy.

4. Lehner's Silk.—Lehner employs a solution of nitrated cellulose in ether and methyl alcohol, to which he adds a solution of natural silk in glacial acetic acid.* The thread is coagulated by passage through a mixture of turpentine, chloroform, and juniper-oil, and is afterwards treated with a solution of sodium acetate.†

Silk-like filaments may be obtained from a solution of cellulose in zinc chloride. The liquid may be easily spun, but the thread which is formed is too weak to be employed as a substitute for silk. The solution is principally used for the manufacture of filaments for incandescent electric lamps. A better solution is obtained by using alkali-cellulose in place of cellulose (Bronnert).

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* Lehner's silk is now produced by much the same means as that of Chardonnet, and the fibre is very similar to that of the latter. Lehner at first attempted to obtain a fibre from a mixture of pyroxylin solution with various vegetable gums and oils, with solutions of cotton in copper-ammonium sulphate, and even with solutions of waste silk itself. None of these, however, proved a success, and he reverted to the more simple solution of pyroxylin in combination with a drying oil. He also discovered that the fluidity of the collodion could be materially enhanced by the addition of sulphuric acid, and consequently he was able to work his solution under much less pressure than Chardonnet.

† The manufacture of artificial silk has of late years become an enterprise of commercial importance. There are factories producing pyroxylin silk at Besançon (France), Spreitenbach and Zurich (Switzerland), Wobton (England), and Elberfeld (Germany). The fibres are formed by forcing the ether-alcohol solution of pyroxylin through glass capillary tubes and winding them on frames. As the solution is very viscous, it requires a pressure of 45 atmospheres to discharge it through the capillary openings. It was formerly the custom to carry out the dyeing of pyroxylin silk in the pulp, but this proved to be impracticable, and at present it is chiefly dyed in the form of yarn. The proportion between the price of natural and artificial silk is approximately as follows· Natural silk, $10 per kilogram; pyroxylin silk, $4 75 per kilogram; gelatin silk (vanduara), $2.40 per kilogram.

A solution of cellulose sulphate in caustic soda may be used for the making of artificial silk. The following method is said to be capable of yielding good results: 10 parts of cotton are mixed with 100 parts of sulphuric acid of 1.55 sp. gr., the mass is thrown into water, and the precipitated cellulose sulphate is washed, and then dissolved in 100 parts of caustic soda of 1.12 sp. gr.*   This
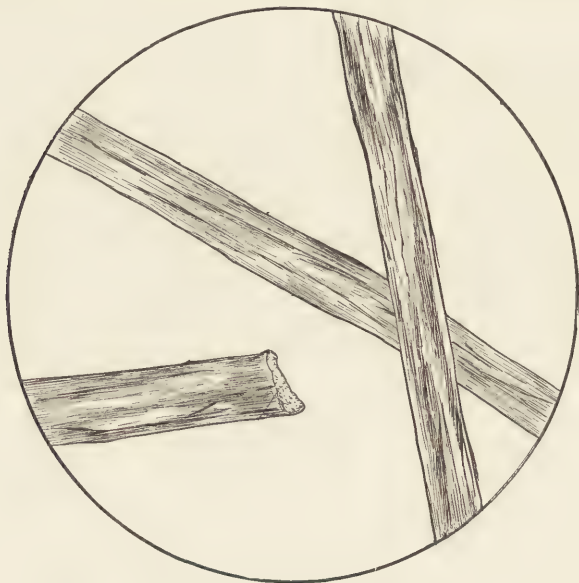
Fig. 65.—Cuprammonium or Pauly Silk.   ($\times$350.)
(Micrograph by author.)

solution is spun in the usual manner, and the thread is subsequently coagulated.

5. Cuprammonium Silk.—Lustra-cellulose threads are also prepared from a solution of cellulose in ammoniacal copper oxide solution (Schweitzer's solution).†   The process in brief

* Vereinigte Kunstseidefabriken of Frankfurt.

† Weston, in 1884, used this solution for the making of incandescent-lamp filaments; Despeissis, in 1890, first thought of applying it to the preparation of artificial silks.   Frémery and Urban, in 1897, under the name of Pauly, patented the first practical process for the manufacture of the fibre.   This silk is now made in considerable quantity by the Vereinigte Glanzstoff-fabriken Actiengesellschaft of Aachen, who have factories at Oberbruch and Niedermorschweiler.   The product is known as *Pauly's silk* or *Parisian artificial silk.*

is as follows: The copper solution is first prepared by treating copper turnings with ammonia in the presence of lactic acid at a temperature of 4° to 6° C. At the end of about ten days the intense blue solution of ammoniacal copper oxide is ready for use. The next step is to obtain mercerized cellulose (cellulose hydrate),* which is done by mixing 100 parts of cellulose with 1000 parts of a solution containing 30 parts of sodium carbonate and 50 parts of caustic soda. This mixture is heated for $3\frac{1}{2}$ hours in a closed vessel under a pressure of $2\frac{1}{2}$ atmospheres. The mercerized cotton thus obtained is washed, dried, bleached with chloride of lime, washed and again dried; after which it is dissolved in the ammoniacal copper oxide solution. The solution (containing 7 to 8 per cent. of mercerized cotton) is filtered, settled, and then spun through capillary tubes under a pressure of 2 to 4 atmospheres. The thread is coagulated by passing through a bath containing 30 to 65 per cent. of sulphuric acid.

6. Viscose Silk.—This is prepared from solutions of cellulose thiocarbonate. It has been made with some degree of commercial success in the United States and Europe. It is principally made in coarse numbers, and is used as an artificial horse-hair. Finer numbers of considerable softness have also been made, for use in braids, passementerie, etc.

Viscose itself is prepared by the action of caustic alkali and carbon disulphide on mercerized cellulose, a gelatinous mass being obtained which is readily soluble in water, giving a yellowish and very viscous solution. Viscose is an alkaline xanthate of cellulose, and its industrial manufacture is carried out in the following general manner: Sheets of crude wood-pulp are ground up with solid caustic soda in a circular-edge roller-mill until a finely divided crumb-like mass is obtained. The product in this form is known as " crumbs," and consists of alkali-cellulose. The excess of moisture is then pressed out, and the material is

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* Ordinary cellulose dissolves but very slowly in Schweitzer's reagent, and moreover the solution is always accompanied by oxidation which changes the cellulose molecule so that it is not fit to spin. Bronnert first proposed the use of cellulose hydrate, and so made the method of practical value.

allowed to lie for some time. This alkali-cellulose is then placed
in a vat provided with a rotary stirrer, where it is treated with
carbon disulphide. The resulting mass is translucent and
gelatinous in appearance and of a clear brown color, and is known
by the name of viscose. Immediately after its formation, the
viscose is dissolved in water and then filtered in order to remove
any cellulose fibre which may not have undergone chemical
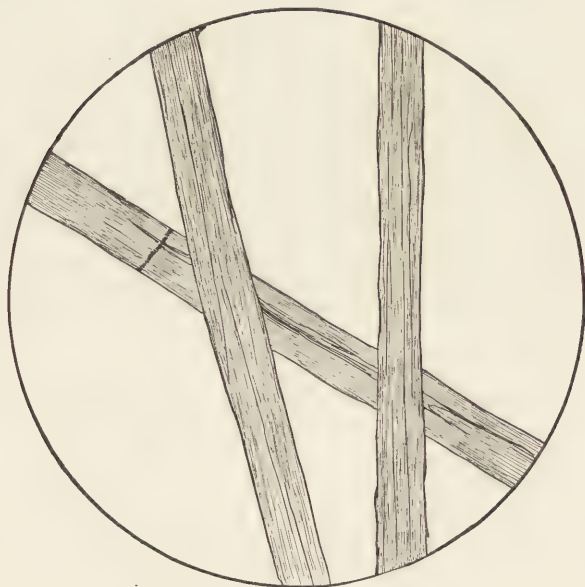
Fig. 66.—Viscose Silk. ($\times$ 350.)
(Micrograph by author.)

transformation. For the successful preparation of artificial
silk it is necessary that the filtering should be as perfect as pos-
sible, for the occurrence of any fibres in the solution will cause
stoppages of the spinnerets and consequently breaks in the
filaments. After filtering the viscose solution is thoroughly
mixed. When the desired degree of fluidity has been attained
(which is indicated by means of a viscosimeter), the viscose solu-
tion is run into suitable reservoirs, in which it is maintained at
a temperature of 32° F. Previous to passing into the spinning-
machines, the viscose solution is filtered a second time, after

which it is run into an apparatus where it is subjected to high pressure for the purpose of forcing out all air-bubbles which are liable to be retained by the viscous solution. This latter treatment is very essential, as the presence of air-bubbles would interfere very materially with the regularity of the spun fibre. The viscose solution then goes into an apparatus which may be called a spinning-frame. This consists of a double series of small pumps, which force the solution through platinum spinnerets pierced with very fine openings, the number of which varies with the size of the thread it is desired to produce. The production, therefore, is proportional to the number of orifices in use; the normal number being about eighteen orifices per thread, while each orifice corresponds to a daily production of about 28 grams (about one ounce). Each spinneret and tube which carries it are immersed in a concentrated solution of ammonium sulphate, for the purpose of coagulating the liquid jet coming from the spinneret by bringing it into immediate contact with the solution. The different filaments forming the threads are at the same time united into one single fibre, and these are carried into a solution of ferrous sulphate (copperas) in order to remove all residual matter left on the fibre from the first bath. The threads then pass into a turbine bobbin, which collects them into skeins, and at the same time gives the thread the desired degree of twist. The fibre, in the form of hanks, is then steeped in an acid solution for the purpose of neutralizing any alkali left in the filaments, the excess of acid being afterwards removed by washing in water. The fibre at this stage has a rather pronounced yellow color, which is removed by bleaching with chloride of lime. Viscose silk has a fine glossy appearance, and possesses a tensile strength about equal to that of pyroxylin silk; like the latter, however, it is also weakened when moistened with water.

7. Properties of Lustra-cellulose.—The chief drawback to the commercial success of collodion silk is its behavior with water. When wetted the fibre loses its original strength to such a degree that it must be handled with great care. Soap solutions and dilute acids have no injurious effect, but alkaline solutions rapidly disintegrate the fibre and finally dissolve it completely. The

material is difficult to dye, on account of the weakening action of
water, and the operation must be carried out with great care.
The dyeing is accomplished without the addition of either soap
or acid to the bath. The basic coloring-matters and some of
the direct cotton colors appear to be the best dyestuffs to employ.

Besides the three processes already given of obtaining collo-
dion silk, there are other methods for the manufacture of this
artificial product. Langhaus * employs as a raw material a prep-
aration from cellulose and sulphuric acid. Cadarat uses nitrated
cellulose, dissolving it in a very complex mixture of glacial
acetic acid, ether, acetone, alcohol, toluol, camphor, and castor-oil.
This forms a plastic mass which is treated with some proteid
substance, such as gelatin or albumin dissolved in glacial acetic
acid. After spinning the fibres are treated with tannin in order
to render them elastic.

Hoepfner † has prepared porous acid-proof fabrics to be
employed for filtering purposes in electrolytic work by using cot-
ton yarn which has been nitrated. The latter can be woven
along with asbestos, glass, or other mineral fibres in the making
of the fabric.

If nitrated cotton be examined under the microscope, a con-
siderable alteration in its appearance will be observed. The
fibres have a much thicker cell-wall, and are consequently stiffer
than those of ordinary cotton. The lumen has either vanished
entirely or become very much contracted, and this appears to be
due to the swelling of the cell-walls. In the walls of the fibre
there will also be noticed numerous fractures or cracks which
often assume a spiral shape. The nitration has evidently rendered
the fibre much more brittle and has decreased its elasticity.

Solutions of nitrated cellulose have been employed for a
number of purposes, such as the production of films for photo-
graphic use, the manufacture of lacquers, etc. The author has

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* This process consists in dissolving cellulose in a mixture of concentrated
sulphuric acid and phosphoric acid, and treating the syrup so obtained with
glyceric ether or ethyl ether. The silk obtained by this process is not of good
quality, and the solution is not very stable, as it soon precipitates more or less
altered cellulose.

† *Färber-Zeit.*, 1897, No. 5.

also successfully utilized such a preparation for the waterproofing of paper and other materials. It also forms an excellent water-proof sizing and stiffening agent for all manner of textile fabrics and hats.

As the solutions of nitrated cellulose possess great viscosity, it is difficult to prepare a very concentrated solution. The addition of formaldehyde or benzol, however, to the ordinary solvents, will increase the dissolving capacity considerably, and also give a more mobile solution. Epichlor- and dichlorhydrins also act as excellent solvents for nitrated cellulose, being capable of dissolving it in any proportion.

The acetate of cellulose (see p. 220) has also been used as a basis for the manufacture of artificial silk. It is dissolved in a suitable solvent and spun in the same manner as collodion silk, the thread being coagulated by passing through a bath of water. With collodion silk the weight of the product obtained (after denitration) is scarcely equal to that of the cellulose used, whereas with acetyl cellulose the weight of the resulting silk corresponds to about twice the weight of the cellulose taken. The silk made from acetyl cellulose, however, is less stable towards acids and alkalies than collodion silk, neither does it dye as readily; and the dyeing is best done by adding the coloring-matter to the solution before spinning. The silk made from acetyl cellulose is known as " cellestion " silk, and is much used for covering electric wires, as it has remarkable insulating properties.

8. Vanduara Silk.*—This is a thread of gelatin, and conse-quently differs from the other artificial silks in that it consists of animal tissue and not vegetable. Due to this circumstance, it has more analogy chemically to true silk than the various cellulose silks. The manufacture of vanduara silk is conducted by forcing an aqueous solution of gelatin through a fine capillary tube; the thread so produced is carried on an endless band through a drying-chamber. The soft gelatin thread, of course, flattens out considerably during this operation, hence the silk

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* Vanduara silk is an English invention, the patentee being Adam Millar. The silk has never appeared on the market as a commercial commodity, and the process does not seem to have met with any marked degree of success.

eventually forms a flat, ribbon-like fibre. After drying and
properly reeling the fibre is treated with vapor of formaldehyde,
which causes the gelatin to become insoluble in water. By vary-
ing the pressure on the gelatin solution, whereby it is forced
through the capillary tube, the thickness of the fibre may be
increased or diminished. The same result may be attained by
varying the speed of the endless band which carries the thread
after coming from the capillary tube. The silk may be dyed
either in the ordinary way in skein form after reeling, or the
gelatin solution may be colored before the thread is drawn out.
The fibre is very lustrous, and if the filaments are drawn fine
enough the silk is soft and pliable.

   9. Comparison of Artificial Silks.—Hassac * gives a com-
parison of several makes of artificial silk. Chardonnet's and
Lehner's silks are very similar in appearance; they are more
lustrous than real silk, but are stiffer, and do not possess the
characteristic feel. Cellulose silk made by Pauly's ammoniacal
copper oxide process is similar to the former in appearance, but
its lustre is even better, and it has the characteristic feel of true
silk. Lehner's silk under the microscope is characterized by
deep longitudinal grooves and small air-bubbles; its cross-
section is highly irregular. Pauly's silk shows fine longitudinal
grooves and minute transverse lines in the centre of the fibres;
its cross-section is regular, approaching a circle or ellipse. Ham-
mel's gelatin silk is almost circular in outline, and is free from
grooves and bubbles; in polarized light it is singly refracting,
while the others are doubly so.

   As the collodion silks always contain some nitrated compound,
they give a blue color with diphenylamin and sulphuric acid.
Water causes all the artificial silks to swell, while alcohol or
glycerol contracts them. In strong sulphuric acid the collodion
silks swell rapidly and dissolve; Pauly's cellulose silk gradually
becomes thinner and dissolves; gelatin silk only dissolves on
strong heating. Chromic acid dissolves all artificial silks in the
cold; real silk dissolves but slowly, while cotton and other vege-
table fibres are unaffected. Caustic potash does not dissolve

* *Chem. Zeit.*, 1900, pp. 235, 267, 297.

the collodion or cellulose silks, but both the gelatin silk and real silk are soluble on boiling. Schweitzer's reagent dissolves collodion and cellulose silks; whereas gelatin silk is insoluble, but stains the liquid a bright violet. Alkaline copper-glycerol solution at 80° C. dissolves real silk immediately. Tussah and gelatin silks dissolve when boiled for one minute; the other silks are not affected. Iodin solution colors artificial silks an intense red, which changes to a transient pale blue on washing with water in the case of collodion silks, though cellulose silk does not show this blue color. Iodin and sulphuric acid stain true silk a yellow color, gelatin silk brown, while collodion and cellulose silks are colored blue.

COMPARISON OF DIFFERENT ARTIFICIAL SILKS WITH REAL SILK (HASSAC).

Silk.	Moisture.		Sp. Gr.	Fibres to Sq. Mm.		Tens. Strength, Kilo. per Sq. Mm.		Elasticity, Per Ct.
	Air-dry, Per Ct.	Saturated, Per Ct.		Wet.	Dry.	Wet.	Dry.	
Real silk............	8.71	20.11	1.36	9710	9710	37.0	37.0	21.6
Chardonnet..........	11.11	27.46	1.52	640	1135	2.2	12.0	8.0
" (Walston)	11.32	28.94	1.53	683	1620	1.0	22.3	7.9
Lehner..............	10.45	26.45	1.51	413	1180	1.5	16.9	7.5
Pauly...............	9.20	23.08	1.50	742	1550	3.2	19.1	12.5
Gelatin.............	13.98	45.56	1.73	265	945	0.0	6.6	3.8

Strehlenert and Westergren give the following figures for the tensile strengths of various natural and artificial silks. The figures indicate the breaking strains in kilograms per square millimetre section:

NATURAL SILKS.

	Dry.	Wet.
Chinese silk.............................	53.2	46.7
French raw silk.	50.4	40.9
French silk, boiled off....................	25.5	13.6
" " dyed red and weighted..........	20.0	15.6
" " blue-black, weighted 110%.......	12.1	8.0
" " black, weighted 140%...........	7.9	6.3
" " black, weighted 500%...........	2.2	

ARTIFICIAL SILKS.

	Dry.	Wet.
Chardonnet's collodion, undyed..	14.7	1.7
Lehner's collodion, undyed..	17.1	4.3
Strehlenert's collodion, undyed.	15.9	3.6
Pauly's cuprammonium, undyed.	19.1	3.2
Viscose silk, early samples.	11.4	3.5
" " latest samples.	21.5	
Cotton yarn (for comparison).	11.5	18.6

10. **Animalized Cotton.**—Cotton may be " animalized "—that is, given the dyeing properties possessed by animal fibres—in a variety of ways. The material may be impregnated with albumin and afterwards steamed; this method is employed to some extent in printing, being used chiefly in connection with the direct cotton colors to prevent their bleeding. A solution of casein may also be used instead of albumin, with similar results. The same property may also be imparted to cotton by treatment with tannic acid and gelatin or lanuginic acid (solution of wool in caustic alkali), but with doubtful results; though Knecht describes a method which is said to give satisfaction, the cotton being impregnated with a solution of lanuginic acid and allowed to dry in the presence of formaldehyde, when the fibre becomes coated with an insoluble film possessing a remarkable affinity for the substantive dyes. Vignon claims that by treating cotton under pressure with ammonia in presence of zinc chloride or calcium chloride, the fibre acquires an increased affinity for the basic and acid dyestuffs. His results, however, have not been confirmed.

A silk-like appearance may also be given to vegetable fibres by treatment with a solution of silk (fibroin) in some suitable solvent, such as hydrochloric, phosphoric, or sulphuric acid, or cuprammonium, etc. The silk employed is made up of scraps and waste which would otherwise be useless. Better results are obtained if the cotton material be treated with a metallic or tannic acid mordant before immersion in the silk solution, and should afterwards be calendered and polished in order to obtain a glossy appearance.

CHAPTER XV.

LINEN.

1. Preparation.—Linen is the fibre obtained from the flax plant, botanically known as *Linum usitatissimum.** The fibre is prepared from the bast of the plant by a process called *retting,* which has for its purpose the separation of the fibrous cellulose from the woody tissue and other plant membranes. Historically linen appears to have been the earliest vegetable fibre employed industrially,† having been used at a much earlier date than cotton. Though grown more or less in every country,‡ at present the cultivation of flax is principally carried on in France, Ireland, Belgium, Holland, Russia, United States,§ and Canada.‖ The

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* Botanists recognize upwards of one hundred species of the flax plant, but, of all these, the only one possessing industrial importance and the only one readily cultivated is the *Linum usitatissimum* (or *L. commun*), which has a blue flower. The North American Indians have long used the fibre of *L. luvisii,* which differs from the ordinary cultivated flax in having three stems growing from a perennial root. The most ancient species of flax brought under cultivation is thought to be *L. angustifolium;* the Swiss lake-dwellers are said to have grown it, as also the ancient inhabitants of northern Italy. The flax cultivated in the eastern countries, in Assyria and Egypt, appears to have been the common variety *L. usitatissimum.*

† Egyptian linen fabrics (mummy-cloths) have been found which are probably over 4500 years old.

‡ The world's annual production of linen is about 1,000,000,000 pounds.

§ Only in the vicinity of Yale, Michigan, at Northfield and Heron Lake, Minnesota, and at Salem and Scio, Oregon, is flax cultivated in America for the production of spinning fibre. In all these localities the seed is saved, and it is doubtful if the industry would yield sufficient profits from the production of the fibre alone to warrant its continuance under present conditions. (*Yearbook,* Dept. Agric., 1903.)

‖ The Department of Agriculture gives the following marks of the commercial grades of flax imported into the United States:

From Russia: Russian flax is known either as *Slanetz* (dew-retted) or *Motchenetz* (water-retted); ungraded fibre is called *Siretz.* The latter comes chiefly

bast tissue, which is used for the fibre, is situated between the bark and the underlying woody tissue (see Fig. 68).

The flax plant is annual in growth and rather delicate in structure. It grows to about 40 inches in height; the stem is slender, branching only slightly at the top, and bears naked, lanceolate, alternate leaves. The flower is mostly sky-blue, though sometimes white; the seed-capsules are five-lobed and globular, and of the size of peas.

The flax plant, after attaining its proper growth, is either cut down or pulled up by its roots, and subjected to a process technically known as *rippling*, the plants being drawn through a machine consisting of upright forks which remove the seeds and leaves.* The remaining stalks are then tied in bundles

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from St. Petersburg, and is known under the names of Bejedsk, Krasnoholm, Troer, Kashin, Gospodsky, Nerechta, Wologda, Jaraslav, Graesowetz, and Kostroma; all these varieties are slanetz. Pochochon, Ouglitz, Rjeff, Jaropol, and Stepurin are motchenetz. From Archangel are brought slanetz varieties known as First Crown, Second Crown, Third Crown, Fourth Crown, First Zabrack and Second Zabrack. From Riga are obtained motchenetz varieties graded from the standard mark K through HK, PK, HPK, SPK, HSPK, ZK, GZK, and HZK.

From Holland: Dutch flax is graded by the marks $\frac{I}{V}$, $\frac{II}{V}$, VI, VII, VIII, IX.

From Belgium: Flemish flax (or blue flax) includes Bruges, Thisselt, Ghent, Lokeren, and St. Nicholas, and is graded as $\frac{II}{IV}$, $\frac{I}{V}$, $\frac{II}{V}$, VI, VII, VIII, IX. Courtrai flax is graded as $\frac{I}{III}$, $\frac{II}{III}$, $\frac{I}{IV}$, $\frac{II}{IV}$, $\frac{II}{V}$, $\frac{I}{V}$, VI.

Furnes and Bergues flax is graded A, B, C, D. Walloon flax is graded II, III, IV. Zealand flax is graded IX, VIII, VII, VI. Friesland flax is graded D, E, Ex, F, Fx, Fxx, G, Gx, Gxx, Gxxx.

From France: French flax is known by the districts of Wavrin, Flines, Douai, Hazebrouck, Picardy, and Harnes.

From Ireland: Irish flax comes as scutched and mill scutched, and is known by the names of the counties in which it is raised.

From Canada: This flax has no standard of marks or qualities.

* Besides being cultivated for its fibre, the flax plant is also grown for its seed, which yields the valuable oil known as linseed. It possesses good drying qualities, and hence is extensively used for the preparation of paints and varnishes. The best seed-flax is grown in tropical and subtropical countries, whereas the best fibre-flax is grown in more northern climates. The seed obtained from the latter variety, though utilized as a by-product, produces only an inferior grade of oil. The oil-cake left after expressing the oil from the seed is an excellent cattle-food and is largely used for this purpose.

and placed in stagnant water, where they are allowed to re-
main for a number of days. Active fermentation soon starts,
resulting in the decomposition of
the woody tissues enclosing the
cellulose fibres. When the proc-
ess has gone sufficiently far, the
bundles of fermented stalks are
removed and passed through a
number of mechanical operations,
whereby the decomposed tissues
are removed and the linen fibres
are isolated in a purified condi-
tion. This method of retting
with stagnant water is known as
" pool-retting." As the fermen-
tation causes the evolution of
considerable gas, in order to keep
the bundles of stalks submerged,
they are loaded with stones or
boards. The time of steeping in
the water varies with circum-
stances from five to ten days.*
Another method of retting is to
steep in running water. The
famous Courtrai flax of Belgium
is retted in this manner in the
river Lys. The flax-straw, after
pulling, is placed in crates and
submerged in the water of this

Fig. 67. — The Ancient Flax Plant
Linum angustifolium.
(After Bulletin U. S. Dept. Agric.)

stream for a period of four to fifteen days, depending on the

* Dodge gives the following notes relative to the retting of flax: "For dew·
retting a moist meadow is the proper place, the fibre being spread over the groun٦
in straight rows at the rate of a ton to an acre. If laid about the 1st of October
and the weather is good, a couple of weeks will suffice for the proper separation
of the fibre and woody matter. For pool-retting the softest water gives the best
results, and where a natural pool is not available, such as the bog-holes' in Ireland,
'steep pools' will have to be built. A pool 30 feet long, 10 feet wide, and 4 feet
deep will suffice for an acre of flax. Spring water should be avoided, or, if used,

temperature and other conditions. Courtrai flax is of a creamy
color, whereas pool-retted flax has a rather dark bluish brown
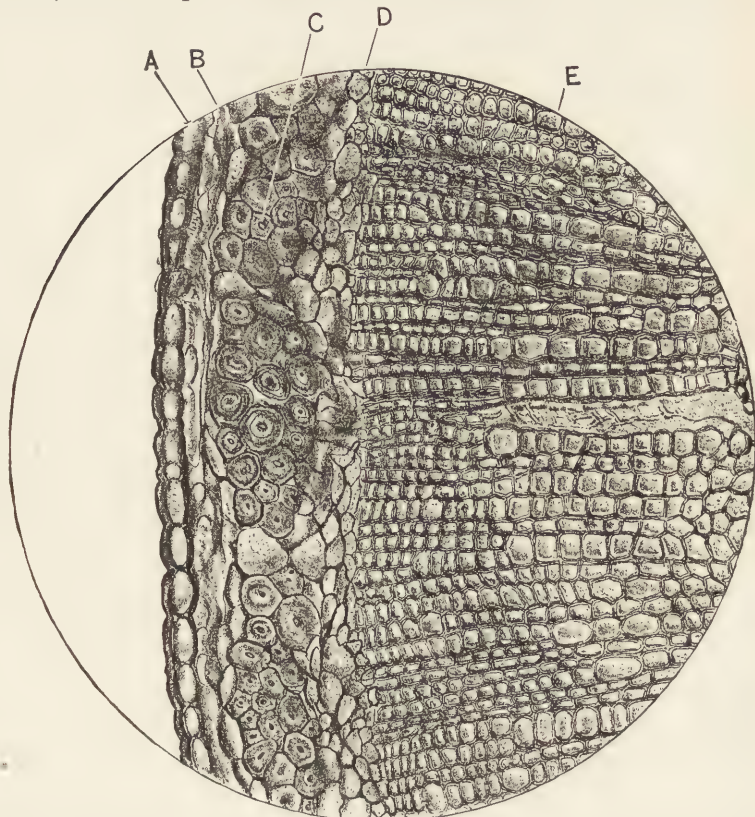
Fig. 68.—Cross-section of Flax-straw.—*A*, layer of cuticular cells; *B*, interme-
diate layer of cortical parenchym; *C*, bast fibres in groups, being the flax
fibres proper (note secondary thickening of cell-walls); *D*, cambium layer;
E, woody tissue. (Cross and Bevan.)

the pool should be filled some weeks before the flax is ready for it, in order to
soften the water. It should be kept free from all mineral and vegetable impuri-
ties. The sheaves are packed loosely in the pool. . . . Fermentation is shown
by the turbidity of the water and by bubbles of gas. . . . If possible, the thick
scum which forms on the surface should be removed by allowing a slight stream
of water to flow over the pool. The fibre sinks when decomposition has been
carried to the proper point, though this is not always a sure indication that it is
just right to take out. In Holland, the plan is to take a number of stalks of aver-
age fineness, which are broken in two places a few inches apart. If the woody
portion or core pulls out easily, leaving the fibre intact, it is ready to come out.
The operation usually requires from five to ten days."

color. The excellent qualities of the Courtrai flax are said
to be due to the action of the soft, slowly running, almost
sluggish waters of the river Lys, and to the peculiar ferment
existing therein. Another method employed for obtaining the
fibre from flax is known as dew-retting, as the flax-straw is spread
out in a field and exposed for a couple of weeks to the action of
the dew and the sun. Dew-retting, however, gives the most un-
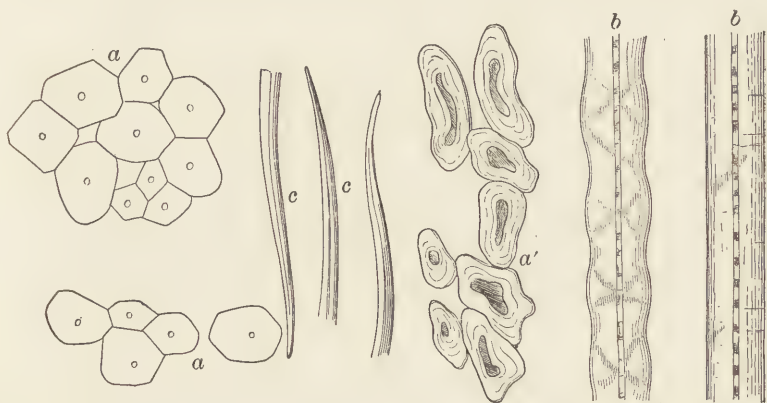
FIG. 69.—Flax Fibres. (×400.) *a*, *a'*, cross-sections; *b*, longitudinal views;
c, ends. (After Cross and Bevan.)

even and least valuable product of the three methods employed,
and the fibre is rather dark in color. There have also been
several chemical methods proposed for retting flax, such as heat-
ing with water under pressure, boiling with solutions of oxalic
acid, soda ash, caustic soda, etc. None of these, however, have
proved of any industrial value, and the older natural methods are
still adhered to. Additions of various chemicals to the retting
waters have at times proved of value, hydrochloric or sulphuric
acid sometimes being used to advantage.*

The intercellular substance holding the flax fibres together

* Schenk's method of retting is to steep in warm water, a constant temperature
of 35° C. being maintained. It is said that the fermentation may be completed
by this method in fifty to sixty hours, and gives a larger yield and a better product
than the natural processes of retting. In steam-retting, the bundles of flax-straw
are placed in iron cylinders and heated with live steam or hot water under pressure,
but the process does not appear to be successful.

consists mostly of calcium pectate, and the real object of retting is to render this substance soluble, so that it may be removed by the after-processes of treatment. Winogradsky has succeeded in isolating the particular organism * that is the active agent in the pectin fermentation.† It is an anaerobic bacillus which readily ferments pectin matters, but has no action on cellulose.‡ By adding salts promoting the growth of the bacillus to the water employed in retting, it has been found possible to reduce the time of retting very considerably. It has been claimed that fatty acids exert a solvent action on the resinous and pectin matters present in vegetable fibres, and a method for the decortication of flax and other bast fibres has been devised as follows: The

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* This organism is the *Bacillus amylobacter.*

† The substances classified in a general way as "pectin matters" form the intercellular matter between the elemental cells of the bast fibres, and serve the purpose of a cementing medium to hold the small elements of the fibre together.   Their character is that of a resinous gum.   By certain investigators this resinous matter has been given the name *pectose.*   It is hardly likely, however, that this substance consists of a single chemical compound, but it is more probably a mixture of several chemical individuals.   By heating with dilute acid, pectose is converted into a series of products which have received considerable attention from botanical chemists; the products include *pectin, para-pectin, meta-pectin, pectosic acid, pectic acid, para-pectic acid, meta-pectic acid,* etc.   Pectin and especially para- and meta-pectin are soluble in water, whereas pectic acid is not.   Therefore, if it is desirable to separate the elements of a vegetable tissue, it is necessary to stop the action of the retting agents before the formation of pectic acid.   In the case of the preparation of linen, however, it appears to be necessary not to dissolve out all the pectose derivatives from the fibre, but to allow of the formation of some pectic acid, as this makes the surface of the fibre more brilliant (Lecomte, *Textiles végétaux*) and leaves it stronger and more elastic.

‡ The water-retting of flax is a biological process induced by the action of definite organisms, the chief of which is an anaerobic *Plectridium,* which in the absence of air ferments the pectin substances of the cellular material uniting the parenchymous tissues, and thus causes a loosening of the bast fibres.   The exclusion of oxygen, which is necessary that the fermentation may be set up, is brought about by numerous oxygen-consuming bacteria and fungi.   The products formed by the fermentation of the pectin substances are hydrogen and carbon dioxide and organic acids, especially acetic and butyric and small quantities of valeric and lactic acids.   The injurious action of the acids produced, especially butyric acid, may be considerably diminished by adding alkali or lime to the retting liquid.   It is also advantageous to inoculate the liquid at the beginning of the retting with pure cultures of the anærobic *Plectridium.* (See Störmer, *Chem. Centr.,* 1905, p. 41.)

raw fibres are impregnated with boiling soap solutions, after which ammonium chloride is added, which liberates the fatty acids. After several hours' treatment these dissolve all gummy and resinous matters; the fibres are then treated with weak caustic alkali, after which they are washed and dried, when they should be thoroughly disintegrated. Good results are said to be obtained by this method.

The flax stalks, after being deprived of their leaves and seeds by rippling, are known as flax-straw. The latter in the air-dry condition contains from 73 to 80 per cent. of wood, marrow, and bark, and 20 to 27 per cent. of bast. The general structure of flax-straw, and of bast stalks in general, is shown in the schematic drawing (Fig. 70).

The linen fibre as it is obtained from the plant and as it appears in trade is in the form of filaments, the length * of which varies considerably with the manner and care employed in decorticating, and may be from a few inches to several feet.† These filaments are composed structurally of small elements or cells, consisting of practically pure cellulose. They are uniformly thick, and average 12 to 25 μ in diameter and 25 to 30 mm. in length. Their structure is rather regular, being cylindrical in shape, though somewhat polygonal in cross-
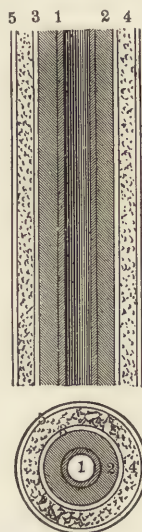
FIG. 70.—Diagram of Flax-straw. 1, marrow; 2, woody fibre; 3, cambium layer; 4, bast fibre; 5, rind or bark. (After Witt.)

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* Flax fibre is from 12 to 36 inches in length, silvery gray when dew-retted, yellowish white when water-retted, capable of fine subdivision, soft and flexible, and is the strongest of the fine commercial bast fibres. It is used for making linen sewing thread, shoe thread, bookbinders' thread, fishing-lines, seine twine, the better grades of wrapping twine, and knit underwear, and for weaving into handkerchiefs, towelling, table-linen, collars and cuffs, shirt-bosoms, and dress-goods. The finer grades of linen damasks are imported, as the weaving of these goods is slow work, and requires a kind of labor not commonly found in this country. (*Yearbook*, Dept. Agric., 1903.)

† Good flax should average 20 inches in length and be free from fibres less than 12 inches in length.

section. A peculiarity in the appearance of the cells is the occurrence of faintly marked " dislocations " or so-called " nodes " extending transversely and often in the form of an " X." These nodes may be made more apparent by staining with methyl violet or chlor-iodide of zinc solution. The cell-wall is quite uniform in thickness, and the lumen or internal canal is very narrow, and often is but faintly apparent as a dark line. The cross-section of the linen fibre shows no yellow circumferential stain when treated with sulphuric acid, though the lumen shows up as a yellow spot. Wiesner gives the following dimensions of several varieties of flax filaments: *

Kind of Flax.	Mean Length of the Purified Flax Fibre, mm.	Mean Breadth, mm.
Egyptian.	960	0.255
Westphalian.	750	0.114
Belgian Courtrai.	370	0.105
Austrian.	410	0.202
Prussian.	280	0.119

2. Chemical and Physical Properties.—The flax fibre appears to consist of pure cellulose † and shows no signs at all of being lignified. It becomes strongly swollen by treatment with

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* Dodge gives the following dimensions for the elements of the flax fibre: Length, 0.157 to 2.598 inches; mean, about 1 inch; diameter, 0.006 to 0.00148 inch; mean, 0.001 inch.

† In order to isolate pure flax cellulose, Cross and Bevan have recommended the following procedure: The non-cellulosic constituents of flax are pectic compounds which are soluble in boiling alkaline solutions. The proportion of such constituents varies from 14 to 33 per cent. in different varieties of flax. They may be completely extracted by first boiling the fibre in a dilute solution of caustic soda (1 to 2 per cent.); the residue will consist of flax cellulose, with small remnants of woody and cuticular tissue, together with some of the oils and waxes associated with the latter. By treatment with a weak solution of chloride of lime, the woody tissue is decomposed, and is then removed by again boiling in dilute alkali. The remaining cellulose is then further purified from residual fatty and waxy matters by boiling with alcohol and finally with ether-alcohol mixture. Flax cellulose prepared in this manner appears to be chemically indistinguishable from cotton cellulose.

Schweitzer's reagent (see Fig. 71), but, unlike cotton, it does not completely dissolve therein.*

The *color* of the best varieties of flax is a pale yellowish white. Flax retted by means of stagnant water, or by dew, is a steel gray, and Egyptian flax is a pearl gray. The pale yellow color of flax is due to a natural pigment, but the other color arises from the decomposition of the intercellular matter, which is left as a stain on the fibre. Flax that has been imperfectly retted shows a
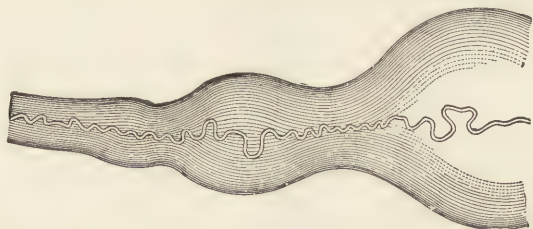
FIG. 71.—Cell of Flax Fibre Treated with Schweitzer's Reagent. (×400.) Showing insoluble cuticle of inner canal. (After Wiesner.)

greenish color. The natural color of linen is readily bleached by solutions of chloride of lime in a manner similar to the bleaching of cotton. But the linen fibre suffers considerable deterioration thereby. There are four grades of linen-bleaching—quarter, half, three-quarters, and full bleach. The whiter the fibre is bleached the weaker it becomes.† The *lustre* of linen is quite pronounced and almost silky in appearance; flax that is overretted is dull in appearance. Egyptian flax is also dull, due to the cells being coated with residual intercellular matter.

The flax fibre is much stronger than that of cotton, though overretted flax is brittle and weak.‡

* In swelling the fibre blisters considerably, but not in as regular a manner as cotton. The inner layers of the cell withstand the action of the reagent the longest and remain floating in the liquid, like the cuticle of cotton. Parenchymous and intercellular matter adhering to the fibre also remains undissolved in the reagent.

† In determining the size (or number) of bleached linen yarns, the loss in bleaching is fixed at 20 per cent. for full, 18 per cent. for three-quarters, and 15 per cent. for one-half bleach.

‡ According to Spon, samples of flax fibre exposed for two hours to steam at 2 atmospheres, boiled in water for three hours, and again steamed for four hours, lost only 3.5 per cent. in weight, while Manila hemp under these conditions lost 6.07, hemp 6.18 to 8.44, and jute 21.39 per cent.

As flax is a better conductor of heat than cotton, linen fabrics always feel colder to the touch than those made from cotton.

The bast-cells of the flax fibre may be isolated by treatment with a dilute chromic acid solution. They are cylindrical in form and taper to a point at each end. At the middle they measure 12 to 26 μ, with an average of about 15 μ.* The length varies from 4 to 66 mm., with an average of about
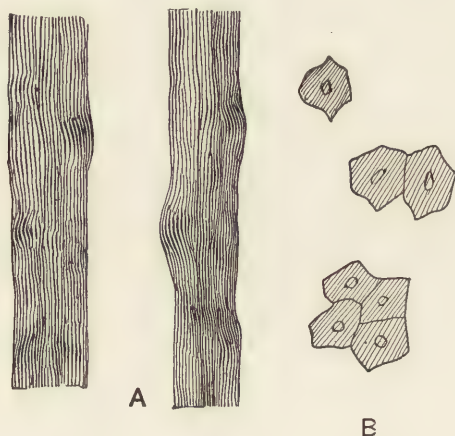
FIG. 72.—Flax Fibre. ($\times$300.) *A*, longitudinal view, showing jointed structure and tracing of lumen; *B*, cross-sections.

25 mm. The ratio of the length of the cell to its breadth is about 1,200. Under the microscope the surface of the cell appears smooth or marked longitudinally, with frequent transverse fissure lines and jointed structures. On treatment with chlor-iodide of zinc the latter are colored much darker than the rest of the cell and are thus rendered more apparent. The lumen appears in the centre of the cell as a narrow yellow line, and it is usually completely filled with protoplasm. With iodin and sulphuric acid linen gives a blue color, which, however, develops less quickly than with cotton; with tincture of madder an orange color is produced, while fuchsin (followed with ammonia) gives a permanent rose color in contradistinction to cotton. These

* According to Vétillard, 15 to 37 μ, with an average of 22 μ.

tests, however, are only applicable to unbleached linen, for the cellulose of bleached linen shows little or no chemical difference from that of cotton. In cross-section the cells of flax are polygonal, with rounded edges, show a small lumen, and a relatively thick cell-wall (see Fig. 72). In these respects they are very similar to hemp, but may be distinguished from the latter, however, in that they do not aggregate in thick bundles, but are more or less isolated from each other, so that the cross-section frequently shows but one cell, and seldom more than three or four (see Fig. 72).*

The following analyses show the composition of two typical specimens of flax (H. Müller):

	I. Per Cent.	II. Per Cent.
Water (hygroscopic)...................	8.65	10.70
Aqueous extract......................	3.65	6.02
Fat and wax..........................	2.39	2.37
Cellulose............................	82.57	71.50
Ash (mineral matter) †	0.70	1.32
Intercellular matter...................	2.74	9.41

Highly purified flax appears to approximate very closely to both the composition and chemical properties of cotton. The ordinary flax fibre of trade may be said to contain about 5 per cent. less of cellulose than cotton, there being about that much more impurity present in the form of intercellular matter and pectin bodies.‡   Linen, however, appears to be free from woody

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* Other differences from hemp exhibited by the linen fibre are: (*a*) the cross-section does not show an external yellow layer of lignin when treated with iodin and sulphuric acid; (*b*) it gives reactions for pure cellulose only, that is, iodin and sulphuric acid color the fibre a pure blue, and anilin sulphate gives no color, though at times there are shreds of parenchymous tissue present which are colored yellow by this latter reagent and appear to be lignified; (*c*) the lumen of the hemp fibre is seldom filled with yellowish protoplasm like that of the linen fibre; (*d*) the linen fibres end in sharp points, whereas those of hemp do not.

† According to Wiesner, the ash of the linen fibre amounts to from 1.18 to 5.93 per cent., and shows no evidence of crystals.

‡ The flax fibre contains a certain wax-like substance, varying in amount from 0.5 to 2 per cent. It may be extracted from the fibre by means of benzene or ether. The color of the wax obtained varies with that of the flax from which it is obtained. It has a rather unpleasant odor, resembling flax itself. Its melting-point is 61.5° C., and its specific gravity at 60° F. is 0.9083. According to Hofmeister, this wax consists of 81.32 per cent. of unsaponifiable waxy matter

or lignified tissue, as it gives none of the reactions for these.   The
linen fibre swells up greatly when treated with an ammoniacal
solution of copper oxide, but, unlike cotton, it does not exhibit the
peculiar sausage-shaped appearance, nor does it dissolve com-
pletely.   The hygroscopic moisture in linen is about the same as
in cotton; in fact, all vegetable fibres appear to contain approxi-
mately the same amount (from 6 to 8 per cent.).*
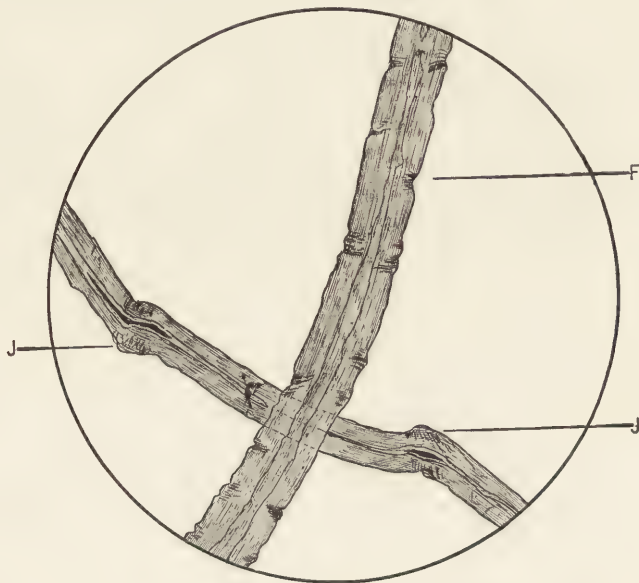
FIG. 73.—Flax Fibre. (×300.)   Stained with methyl violet.   J, joint-like forma-
tions;   F, fissure-like markings.   (Micrograph by author.)

Due to differences in structure, linen is more easily disinte-
grated than cotton, and consequently does not withstand the

and 18.68 per cent. of saponifiable oil.   Of the latter, 54.49 per cent. is free fatty
acid.   The waxy matter has a melting-point of 68° C., and apparently is a mixture
of several bodies.   The principal one resembles ceresin, and there are also present
ceryl alcohol and phylosterin.   The saponifiable matter appears to contain small
quantities of soluble fatty acids, like caproic, stearic, palmitic, oleic, linolic, lino-
lenic, and isolinolenic.

   * The amount of "regain" allowed in the conditioning of linen at Roubaix is from
10 to 12 per cent.   Wiesner gives the amount of hygroscopic moisture in linen as
5.7 to 7.22 per cent.   The Turin Congress fixed the regain for linen at 12 per cent.

action of boiling alkaline solutions, solutions of bleaching powder, or other oxidizing agents, etc., as well as cotton.

Towards mordants and dyestuffs, etc., linen does not react as readily as cotton, hence its manipulation in dyeing is more difficult. In general, however, it may be said that the dyeing and treatment of linen are practically the same as with cotton.

The oil-wax group of constituents in the flax fibre plays an important part in the spinning * of this fibre, and the failure of many of the artificial processes of retting flax may be attributed to the fact that the fibre is left with a deficiency of these constituents. In the breaking down of the cuticular celluloses, whether in the retting or in the bleaching processes, these waxes and oils are separated. Their complete elimination from the cloth necessitates a very elaborate treatment, such as is represented by the "Belfast Linen Bleach."

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* Linen yarns are known as hand-spun or machine-spun; the former are softer and smoother and more elastic, but uneven and less rounded in form, while machine-spun yarns are stiff and rough, but of uniform thickness and perfectly round. According to the method of spinning, linen yarns are also known as dry-spun or wet-spun; the former have greater firmness, but higher numbers can be obtained by wet-spinning. Tow yarns are prepared from waste, and are characterized by numerous knots due to particles of shives. In the English system, the counts of linen yarns are expressed by the number of leas in a pound, each lea measuring 300 yards. To obtain the count of cotton yarn corresponding to the count of linen yarn, the latter number is divided by 2.8. In the French system, the count of linen yarns is the number of hanks of 1000 metres contained in 500 grams. In the Austrian system, the count indicates the number of hanks to 10 English pounds, each hank containing 3600 ells (1 ell = 30.68 inches).

CHAPTER XVI.

JUTE, RAMIE, HEMP, AND MINOR VEGETABLE FIBRES.

1. Jute is a fibre obtained from the bast of various species of *Corchorus*, growing principally in India and the East Indian Islands.* The most important variety is *Corchorus capsularis* or Jew's mallow, which is grown throughout tropical Asia not only as a fibre plant, but also as a vegetable. Other varieties are *C. olitorius*, *C. fuscus*, and *C. decemangulatus;* the latter two, however, yield but a small proportion of the jute fibre to be found in trade.† The jute plant grows to a height of from 10 to 12 feet and its fibrous layer is very thick, so that it yields from two to five times as much fibre as flax.

The *Corchorus capsularis* is an annual plant, growing from 5 to 10 feet in height, with a cylindrical stalk as thick as a man's finger, and seldom branching near the top. The leaves, which are of light green color, are from 4 to 5 inches long by 1½ inches broad

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* Jute was first introduced into Europe about the year 1795. It has been used for spinning since 1830.

† The commercial fibre known as Chinese jute is not a variety of jute at all, but is derived from *Abutilon avicennæ* or Indian mallow. The latter grows extensively as a weed in America. The bast fibre is white and glossy, and has considerable tensile strength. It is also used for the making of paper stock. Chemically it appears to consist of bastose, and hence resembles jute in its behavior towards dyestuffs. The plant produces about 20 per cent. of fibre, but is of doubtful economic value. Another somewhat similar variety is the *Abutilon incanum*, which grows in Mexico; it is said that the Indians used the fibre from this plant for making hammocks, ropes, and nets, which are so durable that they last from seven to ten years in constant use. There are also several East Indian species of *Abutilon*, among which may be named *A. indicum*, *A. graveolens*, *A. muticum*, and *A. polyandrum*, all of which are fibre plants suitable chiefly for cordage; the latter yields a long silky fibre resembling hemp. The *A. periplocifolium*, growing in tropical America, yields a very good bast fibre, quite long, and of a creamy yellow color.

towards the base, but tapering upward into a long sharp point with edges cut into saw-like teeth, the two teeth next the stalk being prolonged into thistle-like points. The flowers are small and of a yellowish white color, coming out in clusters of two or three together opposite the leaves. The seed-pods are short and globular, rough and wrinkled (see Fig. 74, *A*). The *C. olitorius* is precisely like the former in general appearance, shape of leaves,

A   B

FIG. 74.—*A*, seed-vessels of *Corchorus capsularis; B*, seed-vessels of *Corchorus olitorius.* (After Bulletin U. S. Dept. Agric.)

color of flower, and habits of growth; but it differs entirely in the formation of the seed-pod, which is elongated, almost cylindrical, and of the thickness of a quill (see Fig. 74, *B*).

The preparation of the fibre from the jute plant is a rather simple operation. The stalks are freed from leaves, seed-capsules, etc., and retted by steeping in a sluggish stream of water. After a few days the bast becomes disintegrated, and the retted stalks are pressed and scutched. The fibre so obtained is remarkably pure and free from adhering woody fibre and other

tissue. The prepared fibre usually has a length of from 4 to 7 feet, possesses a pale yellowish brown color, though the best qualities are pale yellowish white or silver gray, and exhibits considerable lustre and tensile strength. The ends of the plant, together with the various short waste fibres, appear in trade under the name of " jute butts " or " jute cuttings," and are employed as a raw material for paper-manufacturing.

Kerr (*Report on Jute in Bengal*, 1874) enumerates the following varieties of jute as being the most common in trade: (*a*) *Uttariya*, or northern jute, by far the best variety, as it possesses the best qualities as regards length, color, and strength; it is never equal to the Desi and Deswal varieties, however, in softness. (*b*) *Deswal*, which is next in commercial value, is chiefly desirable on account of its softness, fineness, bright color, and strength. (*c*) *Desi* jute has a long, fine, soft fibre, but it has the defects of being fussy and of a bad color. (*d*) *Deora* jute is strong, coarse, black, and rooty, and is much overspread with runners; it is used for the manufacture of rope. (*e*) *Narainganji* jute is very good for spinning, being soft, strong, and long; but the fibre as it appears in trade has a foxy brown color which detracts from its value, though this defect is apparently due to imperfect steeping. (*f*)*Bakrabadi* excels particularly in color and softness. (*g*) *Bhatial* jute is very coarse, but strong, and is in demand for the manufacture of rope. (*h*) *Karimganji* is a fine variety, long, very strong, and of good color. (*i*) *Mirganji* is of medium quality. (*j*) *Jangipuri* jute is of short fibre, weak, and of a foxy brown color, and not suitable for spinning.

According to Höhnel, the bast-cells of the jute fibre are from 1.5 to 5 mm. in length, and from 20 to 25 μ in thickness, the mean ratio of the length to the breadth being about 90; consequently, the elements of the jute fibre are relatively short. In cross-section the jute fibre shows a bundle of several elements bound together; these are more or less polygonal in outline, with sharply defined angles. Between the separate elements is a narrow median layer (see Figs. 75 and 77), which, however, does not give a much darker color with iodin and sulphuric acid than the cell-wall itself. The lumen is about as wide, or at times even wider,

than the cell-wall, and in cross-section is round or oval. Longitudinally the lumen shows remarkable constrictions or irregular thicknesses in the cell-wall (see Fig. 78), though towards the end of the fibre the lumen broadens out considerably, causing the cell-wall to become very thin. Externally the fibre is smooth and lustrous, and has no jointed ridges or transverse markings, such as seen in linen or most other bast fibres.

In its chemical composition jute is apparently quite different from linen and cotton, being composed of a modified form of
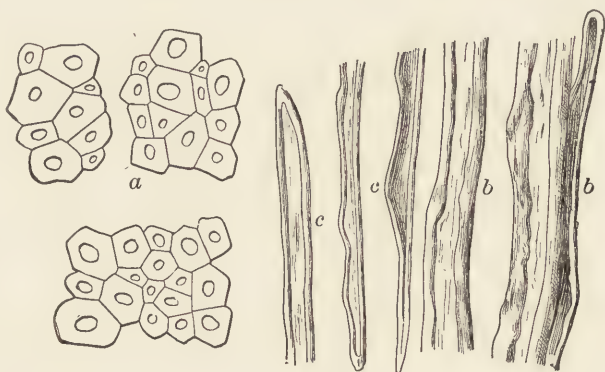
FIG. 75.—Jute Fibre. (×300.) *a*, cross-sections; *b*, longitudinal views; *c*. ends. (After Cross and Bevan.)

cellulose known as lignocellulose or bastose. Bastose, properly speaking, is a compound of cellulose with lignin.* It behaves quite differently from cellulose towards various reagents, its chief distinction being that it is colored yellow by iodin and sulphuric

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* Müller gives the following method for the isolation of pure cellulose from jute: Two grams of the material are dried at from 110° to 115° C. In order to remove wax, etc., it is next treated with a mixture of alcohol and benzol, and is subsequently boiled with very dilute ammonia water. The softened mass is then pulverized in a mortar, and placed in a large, glass-stoppered flask with 100 cc. of water. From 5 to 10 cc. of a solution of 2 cc. of bromin in 500 cc. of water are added, until a permanent yellow is obtained after standing twelve to twenty-four hours. The substance is then filtered, washed with water, and heated to boiling with water containing a little ammonia. After this it is filtered, washed, and again treated with the bromin solution, as above indicated, until a permanent yellow color is obtained. The fibre is then boiled with dilute ammonia, and on filtering and washing leaves a residue of pure white cellulose.

acid, whereas pure cellulose is colored blue. With dilute chromic acid, to which a little hydrochloric acid has been added, jute gives a blue color. When treated with an ammoniacal solution of copper oxide the fibres swell considerably, but do not readily dissolve. With chlor-iodide of zinc jute gives a yellow color. The following table gives the principal reactions used to distinguish cellulose from bastose: *

Reagent.	Cellulose.	Bastose.
Iodin and sulphuric acid..	Blue color	Yellow to brown color
Anilin sulphate and sulphuric acid............	No change	Deep-yellow color
Basic dyestuffs..........	No change	Becomes colored
Weak oxidizing agents....	No change	Quickly decomposes
Schweitzer's reagent......	Quickly dissolves	Swells, becomes blue, and slowly dissolves

Analysis of jute shows it to consist of the following:

Constituents.	Nearly Colorless Specimen.	Fawn-colored Fibre.	Brown Cuttings.
Ash................	0.68		
Water (hygroscopic)†................	9.93	9.64	12.58
Aqueous extract.................	1.03	1.63	3.94
Fat and wax................	0.39	0.32	0.45
Cellulose................	64.24	63.05	61.74
Incrusting and pectin matters........	24.41	25.36	21.29

The ash of jute consists principally of silica, lime, and phosphoric acid; manganese is nearly always present in small amount.

Bastose is dissolved by the usual cellulose solvents, such as zinc chloride and Schweitzer's reagent; and from these solutions the lignocellulose may be precipitated by dilution or acidifying respectively, though the precipitation is never complete, there-

* According to Cross and Bevan, the jute fibre may be regarded as an anhydro-aggregate of three separate compounds: (a) A dextrocellulose allied to cotton, (b) a pentacellulose yielding furfural and acetic acid on hydrolysis; (c) lignone, a quinone which is converted by chlorination and reduction into derivatives of the trihydric phenols.

† According to Wiesner, fresh jute contains about 6 per cent. of hygroscopic moisture and brown jute about 7 per cent. When completely saturated with moisture the former will contain about 23 per cent. and the latter 24 per cent. The Turin Congress adopted a regain of $13\frac{3}{4}$ per cent. for the conditioning of jute.

remaining in solution from 10 to 25 per cent. of the original substance.

The chief chemical difference between jute and the pure cellulose fibres is in the ability of the former to combine directly with basic dyestuffs. In fact it acts in this respect similar to cotton which has been mordanted with tannic acid. Jute is also more sensitive to the action of chemicals in general than cotton or linen. On this account it cannot be bleached with much success, as treatment with alkalies and bleaching powder weakens and disintegrates the fibre to a considerable extent.*

Fig. 76. — Jute Fibre. (×300.) (Micrograph by author.)

The jute fibre is relatively weak when compared with other bast fibres, and the chief reasons for its prominence among the textile fibres are its fineness, silk-like lustre, and adaptability for spinning. The plant is also easy to cultivate, and returns a large yield of fibre. The chief defect of jute is its lack of durability; when exposed to dampness it rapidly deteriorates; and even under ordinary conditions of wear, the fibre gradually becomes brittle and loses much of its strength. The bleached fibre is especially liable to such deterioration; it gradually loses its whiteness, and, evidently due to oxidation, becomes dingy and yellowish brown in color.

Jute is principally used for the making of coarse woven fabrics, such as gunny sacks and bagging, where cheapness is of more consequence than durability.† It also finds considerable use in the tapestry trade, being used as a binding-thread in the weaving

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* Samples of jute fibre exposed for two hours to steam at 2 atmospheres, followed by boiling in water for three hours, and again steamed for four hours, lost 21.39 per cent. by weight, being about three times as great a loss as that suffered by hemp, Manila hemp, phormium, and coir. A similar test for jute with flax, hemp, ramie, and other fibres showed as great a loss, while flax lost less than 4 per cent. and ramie a small fraction under 1 per cent.

† Jute is the cheapest fibre used in American textile manufacturing, and it is employed in greater quantities than any other except cotton and sisal.

of carpets and rugs.   On account of its high lustre and fineness, it is also adapted for the preparation of cheap pile fabrics for use in upholstery.   Of late years a variety of novelty fabrics for dress-goods have also been made from jute, used in conjunction with woolen yarns.   Jute has also been used extensively as a substitute
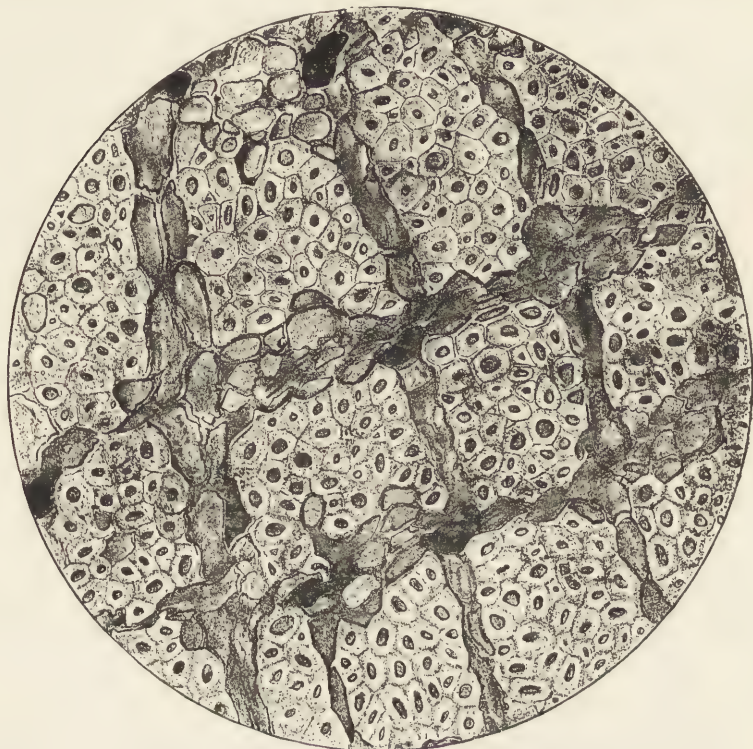
FIG. 77.—Cross-section of Jute-straw. Showing transverse section of portion of bast only, giving the anatomy of the fibrous tissue, the form of the bast-cells, and the thickening of the cell-walls. (Cross and Bevan.)

for hemp, for which purpose the former is rendered very soft and pliable by treatment with water and oil.   A mixture of 20 parts of water with 2.5 parts of train-oil is sprinkled over 100 parts of jute fibre.   It is left for one to two days, then squeezed and heckled, whereby the fibres become very soft and isolated.   Jute is also largely used in the manufacture of twine and smaller sizes of rope.   Owing to its cheapness, it is used to adulterate other more

valuable fibres, but due to its tendency to rapid deterioration, its use in this connection should not be encouraged. The " jute butts " and miscellaneous waste are extensively employed as a raw material in the manufacture of paper.
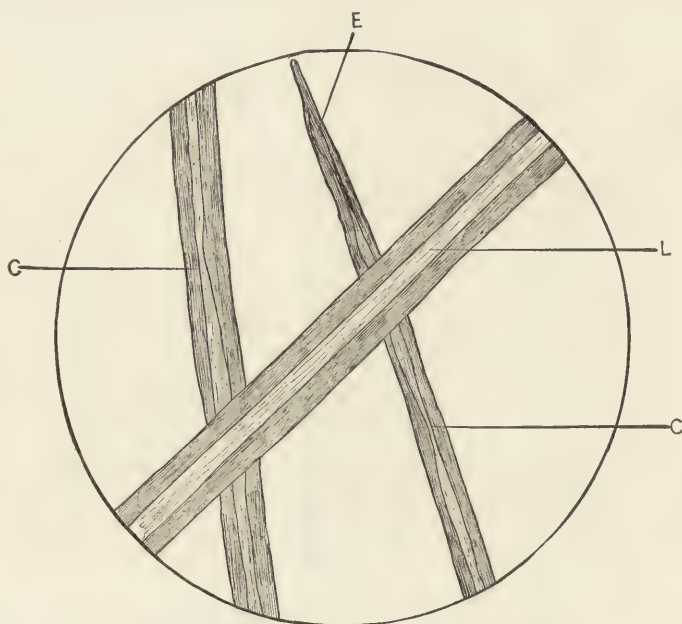
FIG. 78.—Jute Fibre. (×300.)   *L*, lumen; *C*, constrictions in lumen; *E*, end of fibre.   (Micrograph by author.)

2. **Ramie,** or **China Grass,** is a fibre obtained from the bast of the stingless nettle, or *Bœhmeria.* Alt..oug 1 frequent'y confounded in trade, ramie and China grass are in reality two distinct fibres. The former (also known as rhea) is obtained from the *Bœhmeria tenacissima,* which grows best in tropical and subtropical countries. The latter is obtained from *Bœhmeria nivea,* which grows principally in the more temperate climes.*   T. e

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* The ramie plant is of more robust habit and has larger leaves, which are green on both sides; hence the name *green ramie,* which its fibre sometimes receives in trade. The China grass plant has leaves which are white felted beneath; hence the name *white ramie* sometimes given to its fibre.

two species, however, are so similar in nature, and the fibres are so universally confounded with one another, that it is only possible to consider them as a single substance, which will be done under the name of ramie. The plant is a shrub, reaching 4 to 6 feet in height, and is very hardy. It is cultivated largely in China and India, and has also been grown successfully in America.*

The fibre of ramie is very strong and durable, probably ranking first of all vegetable fibres in this respect.† It is also the least

FIG. 79.—Ramie Fibre. (×300.) *a*, sections; *b*, longitudinal view; *c*, ends. (After Cross and Bevan.)

affected by moisture. It has three times the strength of hemp, and the fibres can be separated to almost the fineness of silk. The fibre is exceptionally white in color, being almost comparable to bleached cotton in this respect, and does not appear to

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* The use of China grass or ramie was probably known to the Chinese at a very early period; some writers have also attempted to show that it was used in Egypt several thousand years ago contemporaneously with flax for the preparation of mummy-cloths.

† From experiments made on the tensile strength of isolated filaments of ramie, it appears that this fibre has a breaking strain of from 17 to 18 grams. Ramie degummed in the laboratory of Frémy showed a breaking strain of from 21 to 22 grams, and by very careful degumming it has been possible to attain a strength of from 35 to 40 grams. Isolated fibres of hemp show a breaking strain of only 5 grams.

have any natural coloring matter at all. It also has a high lustre, excelling linen in this respect.*

The following table gives the chief physical factors of the ramie fibre in comparison with the other principal fibres:

	Ramie.	Hemp.	Flax.	Silk.	Cotton.
Tension............	100	36	25	13	12
Elasticity..........	100	75	66	400	100
Torsion............	100	95	80	600	400

Having such excellent qualities as a fibre, it would be natural that ramie should have had considerable attention bestowed upon
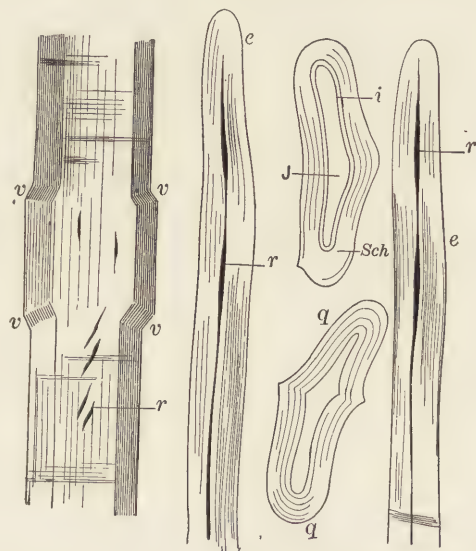
FIG. 80.—Ramie Fibre. (×340.) *v*, swollen displacements; *r*, fissures; *e*, point or end; *q*, cross-sections; *i*, inner layers of fibre-wall; *J*, lumen; *sch*, stratifications. (Höhnel.)

it. The chief difficulty in the way of its universal and wide-spread adoption has been the lack of an efficient process for properly

* *Cottonized ramie* is fibre on which the degumming process has been carried too far, with the result that the individual filaments have been more or less separated into their elements; the fibre is white, but without the characteristic transparency and lustre of ordinary ramie.

decorticating the fibre from the rest of the plant. In China and India, where this fibre has long been employed for the weaving of the finest and most beautiful fabrics,* the decortication of the fibre is carried out by hand. This, of course, would be impracticable in western countries.
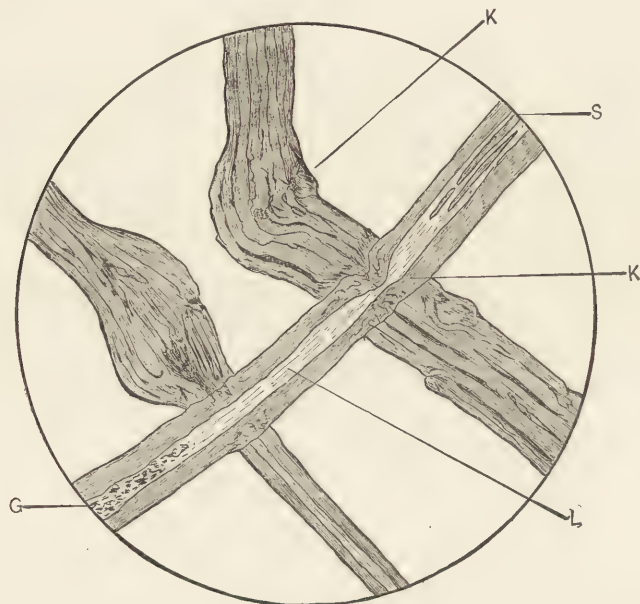
FIG. 81.—Ramie Fibre. (×350.) L, lumen; G, granular matter in lumen; S, long shreds of matter in lumen; K, knots in fibre. (Micrograph by author.)

On French authority it is stated that the yield of decorticated fibre from the green, unstripped stalks amounts to about 2 per cent., and of degummed fibre about 1 per cent. Based on the weight of dry, stripped stalks, the yield of the degummed fibre would be about 10 per cent.

The bast of the ramie cannot be removed from the woody tissue in which it is imbedded by a simple retting, as in the case of flax and other bast fibres. It must undergo a severe mechanical

* The brilliant and transparent fabrics known in China as *A-pou* and sold in England under the name of *grass-cloth* are made from ramie.

treatment, whereby the outer bark is removed.   The long, fibrous tissue so obtained consists of the ramie filaments held together in the form of a ribbon by a large quantity of gum, and before the fibres can be combed out this gum must be removed by chemical treatment.   The gummy matters seem to consist essentially of
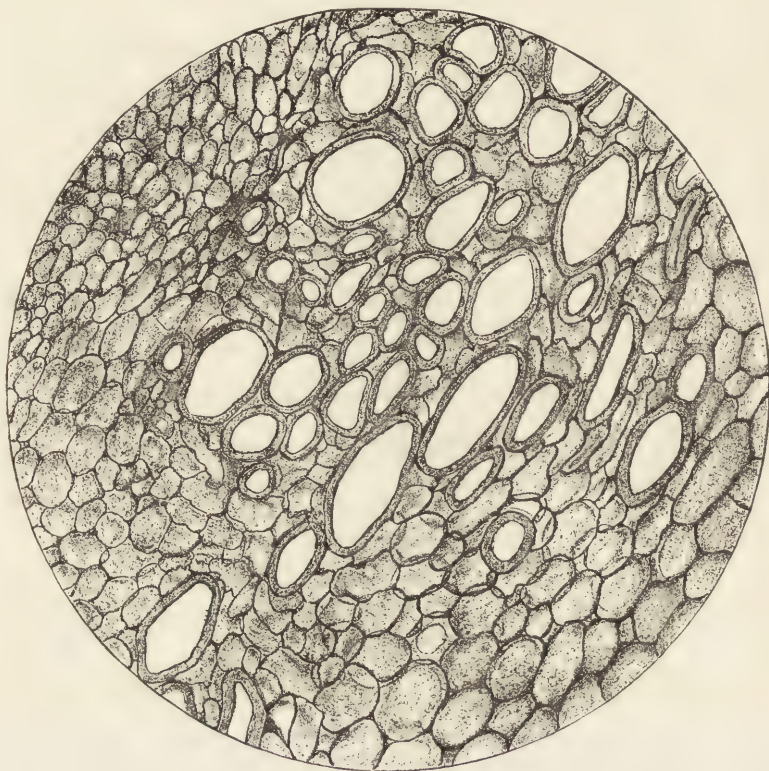
FIG. 82.—Cross-section of Ramie-straw.   Showing transverse section of bast region only; the bast-fibres are to be distinguished by their large area from the adjacent tissue.   (Cross and Bevan.)

pectose, cutose, and vasculose.   In the degumming, the object is to remove these substances without affecting the cellulose of the fibre proper.   The vasculose and cutose may be dissolved by treatment with soap or caustic alkalies employed under pressure. The adhering pectose can then be detached mechanically by washing.

Though ramie has many excellent qualities to recommend it as a textile fibre for definite uses, nevertheless it lacks the elasticity of wool and silk and the flexibility of cotton. As a result it yields a harsher fabric, which has not the softness of cotton. Owing to its smooth and regular surface, it is difficult to spin to fine counts, as the fibres lack cohesion and will not adhere to each other.

Microscopically the ramie fibre is remarkable for the large size of its bast-cells. These are from 60 to 250 mm. in length and

Fig. 83.—Ramie Fibre. (×420.) Showing the longitudinal ridges and knot-like cross-markings. (Micrograph by author.)

up to 80 μ in width. The diameter of the fibre is also characteristically uneven, sometimes narrow with heavy cell-walls and well-defined lumen and at other times broad and flat with an indistinct lumen, but showing heavy striations along the fibre. The ratio of the length of the fibre to its breadth is about 2400. The fibre consists of pure cellulose with no indication of the presence of any lignin as iodin and sulphuric acid give a pure blue stain, and anilin sulphate gives no color. In an ammoniacal solution of copper oxide ramie becomes greatly swollen, but does not dissolve.* Along the fibre, joints and transverse fissures are

* The ramie fibre gives a blue coloration with the chlor-iodide of zinc reagent, and rose-red with chlor-iodide of calcium; *white ramie* gives no coloration with

of frequent occurrence (see Fig. 8ː). The lumen is especially broad and easily noticeable. The ends of the fibre elements have a thick-walled, rounded point, and the lumen is reduced to a line. At places the lumen appears to be more or less filled with granular matter, and sometimes with long uneven shreds of matter, evidently dried-up albuminous matter. The cross-section of the fibre (see Fig. 80) shows usually only a single element or a group of but a few members. The cross-section is also quite large, and is elliptical in shape; the lumen appears open, and frequently contains granular matter. The cross-section also frequently shows strong evidence of stratification. The fibres are frequently very broad, and at these parts are flat and ribbon-like in form, but are never twisted (see Fig. 81).

Müller gives the following analysis of the raw fibre of samples of both China grass and ramie:

Constituent.	China Grass.	Ramie.
Ash.	2.87	5.63
Water (hygroscopic).	9.05	10.15
Aqueous extract.	6.47	10.34
Fat and wax.	0.21	0.59
Cellulose.	78.07	66.22
Intercellular substances and pectin.	6.10	12.70

3. Hemp is a name applied to a large number of bast fibres more or less analogous in appearance and properties.* Hemp

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anilin sulphate, but *green ramie* gives a slight yellow color, which seems to indicate a slight degree of lignifaction in the case of the latter fibre.

* Among the different varieties of hemp appearing in trade may be enumerated the following (Dodge):

Ambari (or brown) hemp.	*Hibiscus cannabinus*
Bengal (or Bombay) hemp.	*Crotalaria juncea*
Black-fellow's hemp.	*Commersonia fraseri*
Bowstring hemp (Africa).	*Sansevieria guineensis*
Bowstring hemp (Florida).	*S. longiflora*
Bowstring hemp (India).	*S. roxburghiana*
Calcutta hemp.	Jute
Cebu hemp.	*Musa textilis*
Colorado River hemp.	*Sesbania macrocarpa*
Cretan hemp.	*Datisca cannabina*

proper, or the so-called *common hemp*, is derived from the bast of *Cannabis sativa*. This is a shrub * growing from 6 to 15 feet in height, and though originally a native of India and Persia, it is now cultivated in nearly all the temperate and tropical countries of the world. At the present time it is quite extensively grown in America,† though not as yet in sufficient amount to satisfy the home consumption. Russia produces an enormous quantity of hemp; in fact, this fibre forms one of that country's staple articles

Cuban hemp......................	*Furcræa cubensis*
False hemp (American)............	*Rhus typhina*
False sisal hemp..................	*Agave decipiens*
Giant hemp (China)...............	*Cannabis gigantea*
Hayti hemp....................	*Agave fœtida*
Ifé hemp.......................	*Sansevieria cylindrica*
Indian hemp.....................	*Apocynum cannabinum*
Jubbulpore hemp (Madras).........	*Crotalaria tenuifolia*
Manila hemp....................	*Musa textilis*
New Zealand hemp (or flax)........	*Phormium tenax*
Pangane hemp...................	*Sansevieria kirkii*
Pita hemp.	*Yucca* sp.
Pua hemp (India)................	*Maoutia puya*
Queensland hemp..........	*Sida retusa*
Rangoon hemp...	*Laportea gigas*
Roselle hemp.	*Hibiscus sabdariffa*
Sisal hemp.....	*Agave rigida*
Sunn hemp.....................	*Crotalaria juncea*
Swedish hemp..................	*Urtica dioica*
Tampico hemp.............	*Agave heteracantha*
Water hemp.............	*Eupatorium cannabinum*
Wild hemp......................	*Maoutia puya*

* The hemp is an annual plant, with a straight stalk, and elongated, highly dentated leaves. The latter have a narcotic odor, and occur in bunches of three, five, or seven. The flower is apetalous and develops into the well-known hemp-seed on maturity. The hemp plant is diœcious; that is, it belongs to the class of plants in which the sexes are divided, some stems bearing only clusters of male flowers (panicles), while others bear only female flowers (catkins). The female plant grows from 6 to 8 feet in height, while the male plant (*fimble hemp*) is shorter.

† Several varieties of hemp are grown in this country; that cultivated in Kentucky and having a hollow stem being most common. China hemp and Smyrna hemp are also grown, and in California Japanese hemp is cultivated and gives a remarkably fine product. Five varieties of hemp appear to be cultivated in Europe: the common hemp, Bologne hemp (known also as Piedmontese hemp or great hemp), Chinese hemp, small hemp (the *Canapa piccola* of Italy), and Arabian hemp. The latter is also known as Takrousi and is chiefly cultivated for its resinous principle, from which hasheesh is obtained.

of export. Poland is also a large producer. French hemp, though not grown to such an extent, is much superior in quality to that from either Russia or Poland, it being fine, white, and lustrous. Italian hemp is also of a very high grade. In India hemp is not grown so much for its fibre as for the narcotic products obtained. Japanese hemp is of excellent quality, and
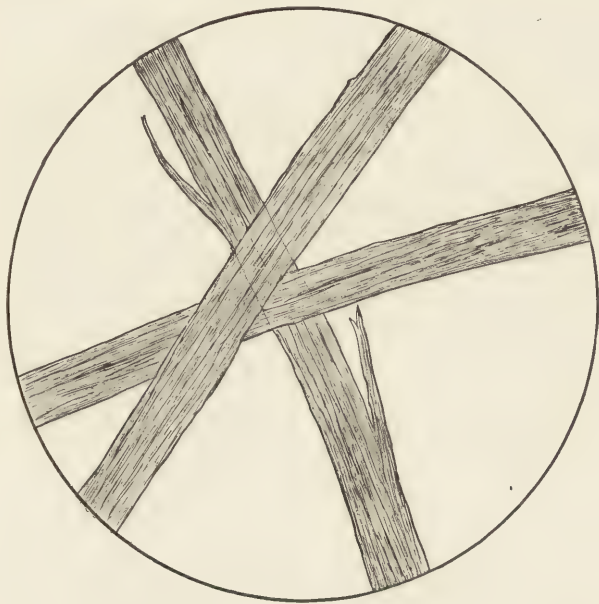
FIG. 84.—Hemp Fibres. (×300.) (Micrograph by author.)

appears in trade in the form of very thin ribbons, smooth and glossy, of a light straw color, and the frayed ends showing a fibre of exceeding fineness. Hemp appears to have been the oldest textile fibre used in Japan.

The hemp fibre is obtained from the plant by a process of retting similar to that employed for flax.* The method of dew-retting is chiefly used; that is, the stalks are spread out in the fields until the action of the elements causes the woody tissue

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* The plant is ready for pulling when the lower leaves become limp and the tip of the stalk turns yellowish. The male plants are pulled first and the female plants about 2 to 3 weeks later.

and gums enclosing the fibres to decompose.*   Retting in pools
of water has been practised to a slight extent, but evidently not
with much success.†   It is said that 100 parts of raw hemp furnish
25 parts of raw fibre or filasse; and 100 parts of the latter yield
65 parts of combed filasse and 32 parts of tow.‡
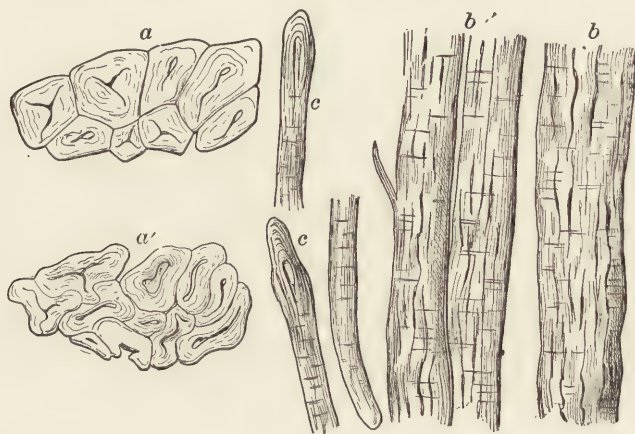
FIG. 85.—Hemp Fibres.   (×300.)   *b*, longitudinal views; *c*, ends; *a* cross-sections.
(After Cross and Bevan.)

The seed of the hemp plant, like that from flax, is also utilized
for the oil it contains; § 100 parts of seed furnish 27 parts of oil.

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* Hemp fibre, prepared by water-retting as practised in Italy, is of a creamy
white color, lustrous, soft, and pliable.   It makes a satisfactory substitute for
flax, and is used for medium grades of nearly all classes of goods commonly made
from flax, except the finer linens.   When prepared by dew-retting, as practised in
this country, the fibre is gray, and somewhat harsh to the touch.   It is used for
yacht cordage, ropes, fishing-lines, linen crash, homespuns, hemp carpets, and
as warp in making all kinds of carpets and rugs.   (*Yearbook*, Dept. Agric., 1903.)

† *Baden hemp*, which is a much-prized variety, is prepared by stripping the
bast from the retted stalks by hand.   The product is entirely free from shives.

‡ The commercial fibre is pearly gray, yellowish or greenish to brown in color,
and from 40 to 80 inches in length.   Its fineness of staple is less than that of linen,
though its tensile strength is appreciably greater.   The best qualities of hemp are
very light in color and possess a high lustre almost equal to that of linen.   The
annual production of hemp fibre is about 600,000,000 pounds.

§ Hemp seed yields a greenish-colored oil having a peculiar odor.   It is used
in the making of green soap for the preparation of artists' colors and varnishes,
and in some localities for the making of oil-gas.   Hemp seed is also used as a
bird food, and in some countries (Russia) is an article of diet.

So this forms an extensive and important by-product in the cultivation of hemp.

Under the microscope the hemp fibre is seen to consist of cell elements which are unusually long, averaging about 20 mm. in length, but varying from 5 to 55 mm. The diameter, however, is very small, averaging 22 μ, and varying from 16 to 50 μ. Hence
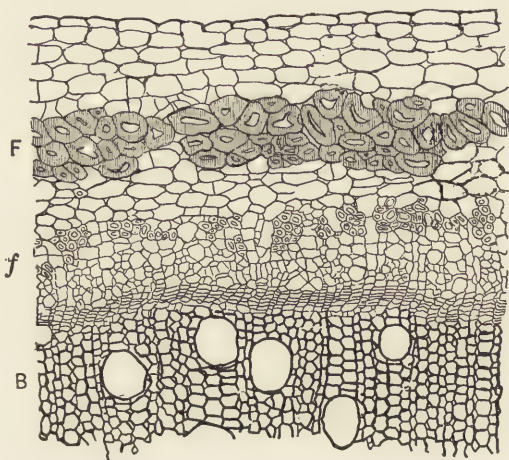
Fig. 86.—Part of Cross-section of Hemp Stalk. ($\times$200.) *B*, woody tissue; *f*, secondary layer of fibres; *F*, main layer of fibres. (After Le Comte.)

the ratio between the length and diameter is about 1000. The fibre is rather uneven in its diameter, and has occasional attachments of fragmentary parenchymous tissue. In its linear structure the fibre exhibits frequent joints, longitudinal fractures, and swollen fissures. The lumen is usually broad, but towards the end of the fibre it becomes like a line (see Fig. 89). It shows scarcely any contents. The ends of the filaments are blunt and very thick-walled, and often possess lateral branches. The cross-section generally shows a group of cells which nearly always have rounded edges and are not so sharp-angled and polygonal as in the case of jute. There is also a median layer between the cells, which is evidenced by it turning yellow on treatment with iodin and sulphuric acid.* In the section the lumen appears irregular

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* The intercellular (median layer) matter which binds the elements of the hemp together contains vasculose, and even the cellulose of the fibre itself appears

and flattened, and does not show any contents. The cell-walls frequently exhibit a remarkable stratification, the different layers yielding a variety of colors on treatment with iodin and sulphuric acid.

When examined under polarized light, hemp shows very bright colors similar to linen and ramie. Hemp also gives the following
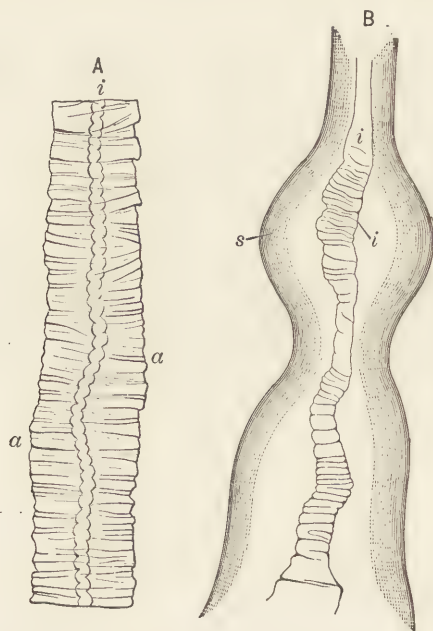
FIG. 87.—Hemp Fibres Treated with Schweitzer's Reagent. ($\times 300$.) *A*, strongly lignified fibre; *B*, fibre free from ligneous matter; *i, i*, skin of inner canal; *a*, external ligneous tissue; *s*, swollen cellulose. (After Wiesner.)

microchemical reactions: (*a*) with iodin-sulphuric acid reagent, bluish green coloration; (*b*) with chlor-iodide of zinc, blue or violet, with traces of yellow; (*c*) chlor-iodide of calcium, rose red with traces of yellow; (*d*) anilin sulphate, yellowish green

to be impregnated with this substance. This is the cause of the stratified appearance of the cell-wall when the fibre is treated with the iodin-sulphuric acid reagent. When the hemp fibre is viewed longitudinally and is treated with the above reagent, a green color is obtained, due to the mixing of the yellow of the vasculose layer and the blue of the cellulose layer. By this means hemp may readily be distinguished from linen, which gives a characteristic blue color.

coloration; (*e*) ammoniacal fuchsin solution, pale-red coloration; (*f*) with Schweitzer's reagent the hemp fibres swell irregularly with a characteristic appearance (see Fig. 87) and after a while dissolve almost completely, leaving only the fragments of parenchymous tissue.

Hemp is sometimes difficult to distinguish microscopically from flax; but the two may readily be told by an examination of the
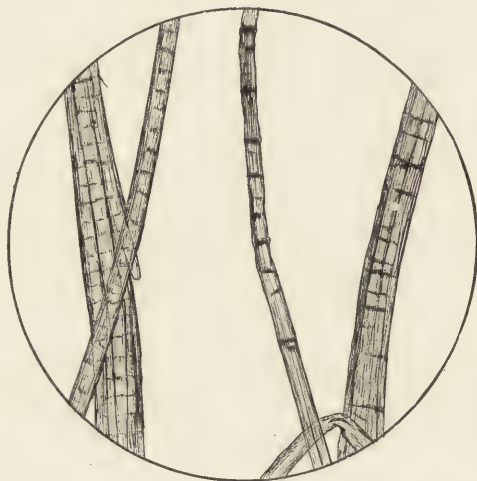
FIG. 88.—Fibres of Hemp. (×300.) Showing longitudinal fissures and transverse cracks and jointed-like structure. (Micrograph by author.)

ends of the fibres, hemp nearly always exhibiting specimens of forked ends, whereas flax never has this peculiarity. The fibres of hemp are also less transparent than those of linen, and the interior canal is often more difficult to distinguish, on account of the numerous striations on the surface. The difference in the appearance of the cross-sections is also of service in discriminating between these two fibres. Again, the parenchymous tissue which frequently occurs as attached fragments to hemp fibres is rich in star-shaped crystals of calcium oxalate, and this is scarcely ever to be noticed in the case of flax. A peculiarity to be noticed in the examination of hemp is the occasional presence of long narrow cells filled with reddish brown matter, insoluble in the ordinary

solvents. These cells occur between the fibres as well as in the bast, and probably contain tannin. They are not to be found in fl x. The behavior of isolated hemp cells with ammoniacal copper oxide solution is also quite characteristic; the cell membrane acquires a blue to a bluish green color, and swells up like a blister, showing sharply defined longitudinal striations.
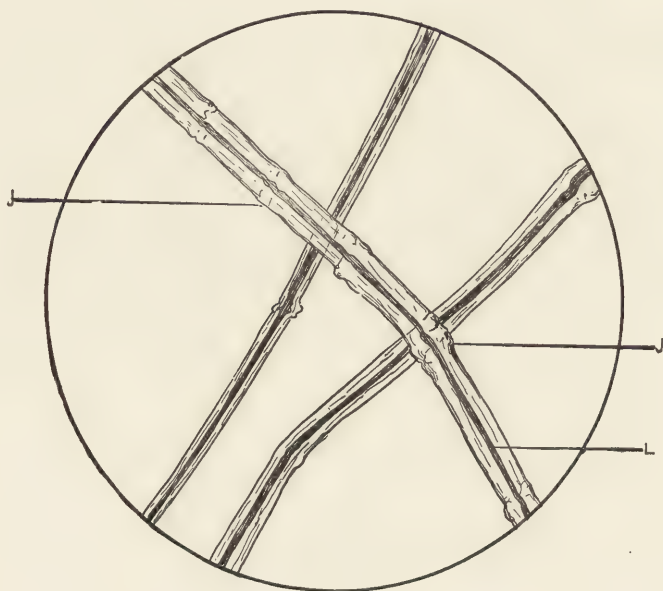
FIG. 89.—Hemp Fibres. (×300.) L, lumen; J, joint-like structure. (Micrograph by author.)

The inner cell-wall remains intact in the form of a spirally wound tube contained inside the strongly swollen mass of the fibre.

The hemp fibre is not composed entirely of pure cellulose, as it gives a yellow to yellowish green coloration with anilin sulphate, and a greenish color with iodin and sulphuric acid. Both hydrochloric acid and caustic potash give a brown coloration, while ammonia produces a faint violet. It appears to be a mixture of cellulose and bastose. Müller gives the following analysis of a sample of the best Italian hemp.

	Per Cent.
Ash.	0.82
Water (hygroscopic).	8.88
Aqueous extract.	3.7
Fat and wax.	0.6
Cellulose.	77.77
Intercellular matter and pectin bodies.	9.31

Hemp appears to contain more hygroscopic moisture than cotton or linen. Samples examined by the author contained
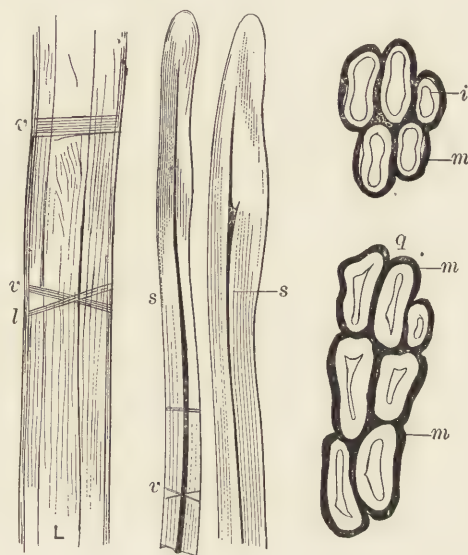
FIG. 90.—Sunn Hemp. (×325.) *L*, view of middle portion; *v*, joints; *l*, lumen; *s*, pointed ends; *q*, cross-sections; *m*, outer layer of fibre; *i*, inner layers. (Höhnel.)

8 per cent. moisture compared with 6 per cent. for cotton under the same conditions. At the Roubaix conditioning house the regain allowed on hemp is 12 per cent., and this same figure was fixed by the International Congress at Turin.

Hemp is principally employed for the manufacture of twine and cordage, for which its great strength eminently adapts it; and, besides, it is a very durable fibre, and is not rotted by water. In this respect it differs very essentially from jute. It is seldom used, however, for woven textiles, as it is harsh and stiff, and not suffi-

ciently pliable and elastic.   It also possesses a rather dark brown color, and cannot be successfully bleached without serious injury to the quality of the fibre.*

FIG. 91.—Leaf and Blossom of *Crotalaria juncea.*   (After Bulletin U. S. Dept. Agric.)

4. Sunn Hemp is the bast fibre of the *Crotalaria juncea;* it is also known by the names of Conkanee, Indian,† Brown, and

* Cuban hemp of trade is the fibre from *Furcræa cubensis,* a plant native to tropical America, and having long leaves in which the fibre is found.   The fibre is of very good quality and is similar to sisal hemp.   Another species, the *F. gigantea,* or giant lily, also gives a good fibre which closely resembles sisal hemp and no doubt is often sold in trade for this latter fibre.   It is also grown in tropical America, and the fibre is called by the natives fique, and is principally employed for the making of bagging, horse blankets, etc.   It is known in Venezuela as *cocuiza.*

† True Indian hemp is the bast fibre from *Apocynum cannabinum;* this fibre is a light cinnamon in color and is long and tenacious.   It was principally employed by the North American Indians who made bags, mats, belts, and cordage

Madras hemp. It grows abundantly in the countries of southern Asia, and is largely used in the manufacture of cordage. It appears to have been one of the earliest fibres mentioned in Sanscrit literature.* The fibre is obtained from the plant by a system of retting very similar to that of flax. The fibre of sunn hemp is of a better quality than jute, being lighter in color, of a better tensile strength, and more durable to exposure.† Dr. Wright gives the following table (page 308) for the strength of several cordage fibres. ‡

from it. Spon mentions Indian hemp under the common name of "Colorado hemp," but this latter name really belongs to the fibre from *Sesbania macrocarpa.*

* It was known in the Institutes of Menu under the name of *sana.* This hemp was also probably known to the Chinese at a very remote date.

† The following tables of comparative tensile strengths for various cordage fibres have been adopted from Royle's work on *The Fibrous Plants of India;* the tests were made on ropes of the same size and 1.2 metres in length.

I. COMPARATIVE STRENGTH, DRY AND WET.

Fibre.	Dry, Kilos.	Wet, Kilos.
Hemp from Calcutta	72	86
Sunn hemp (fresh retted)	51	72
" " (retted after drying)	27	35
Jute (*Corchorus capsularis*)	65	66
" (*C. olitorius*)	51	56
" (*C. strictus*)	47	52
Gambo hemp (*Hibiscus cannabinus*)	52	60
Roselle hemp (*H. sabdariffa*)	41	53
Hibiscus abelmoschus	49	49
Ramie (*Bœhmeria tenacissima*)	110	126

II. COMPARATIVE STRENGTH OF PREPARED ROPES, AND AFTER STEEPING IN WATER 116 DAYS.

Fibre.	Prepared Ropes. Natural.	Tanned.	Tarred.	Water-soaked. Natural.
Hemp, English	47	—	—	Rotted
Hemp, Calcutta	34	63	20	"
Coir	39	—	—	24
Sunn Hemp	31	31	27	Rotted
Jute	31	31	28	18
Linen, Calcutta	17	—	—	Rotted
Agave americana	50	36	35	"
Sansevieria zeylanica	54	33	22	13

‡ According to Roxburgh, similar lines of jute and sunn hemp showed the following comparative tensile strengths:

	Dry.	Wet.
Jute	143	146
Sunn hemp	160	209

	Pounds.
Sunn hemp	407
Cotton rope	346
Hemp	290
Coir	224

In appearance sunn hemp is very similar to hemp, both to the naked eye and under the microscope. The essential distinction between the two is in the cross-section (see Fig. 90), which shows the presence of a very thick median layer of lignin between the individual cells. The lumen in the cross-section is also usually rather thick, and often contains yellowish matter differing in these respects from hemp, in which the lumen is flat and narrow and always empty.* With iodin and sulphuric acid sunn hemp gives a greenish blue coloration, and with chlor-iodide of zinc brownish blue. This would indicate that the fibre is of rather pure cellulose, but enveloped with a layer of lignified tissue.

Müller gives the following analysis of raw sunn hemp:

	Per Cent.
Ash	0.61
Water (hygroscopic)	9.60
Aqueous extract	2.82
Fat and wax	0.55
Cellulose	80.01
Pectin bodies	6.41

5. Ambari or **Gambo Hemp** is an East Indian fibre derived from the bast of *Hibiscus cannabinus*.† The fibre when care-

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* Another variety of *Crotalaria* used for its fibre is the *C. tenuifolia* from which is obtained the Jubbulpore hemp. This fibre is said by some to be superior to that of Russian hemp (*Cannabis sativa*), its relative tensile strength being 95 pounds to 80 pounds for the latter. The fibre is 4 to 5 feet in length, and resembles the best St. Petersburg hemp. The fibre *C. retusa* is also to be found in India under the name of sunn hemp; *C. sericea* and *C. striata* are other species which are also employed for fibre.

† Another variety of *Hibiscus* which is sometimes used as a fibre plant is the *H. esculentus*, or common okra. The bast of this plant at one time attracted considerable attention in the Southern States as a possible substitute for jute in the manufacture of bagging for cotton. The fibre is said to be as white as New Zealand flax, considerably lighter than jute, but more brittle and not so strong. The filaments, however, are smooth and lustrous and quite regular. It is used somewhat in India for the manufacture of twine and cordage, and as an adul-

fully prepared is from 5 to 6 feet in length; it is of a lighter color than hemp, and harsher. Its tensile strength is somewhat less than that of sunn hemp. Like the latter fibre, it is principally used for cordage, though it is also employed in India for the manufacture of a coarse canvas.* In its microscopic characteristics ambari hemp is very similar to jute; the length of the fibre elements varies from 2 to 6 mm. and the diameter from 14 to 33 μ. The median layers of lignin between the cells are broad, and are colored much darker than the inner layers of the cell-wall when

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terant for jute. According to the tests of Dr. Roxburgh, the fibre of Indian okra gave the following results compared with hemp and jute:

	Breaking Strain, Pounds.	
	Dry.	Wet.
Indian okra..................................	79	95
Jute..	113	125
Hemp (Bengal).............................	158	190
Hibiscus cannabinus.......................	115	133
H. sabdariffa.............................	95	117
H. strictus...............................	104	115
H. furcatus..............................	89	92

The bast fibre of *H. tiliaceus* (the *majagua*) has some interest in the fact that, according to the experiments of Dr. Roxburgh, it does not rot when immersed in water for a long period, as most other fibres do. His results were as follows: A cord of this fibre when white had a breaking strain of 41 lbs., when tanned 62 lbs., and when tarred 61 lbs.; a similar cord when macerated in water for 116 days, when white broke with 40 lbs., when tanned 55 lbs., and when tarred 70 lbs. English hemp and Indian hemp when treated in the same manner were found to be rotten, and sunn hemp broke with 65 lbs. and jute with 60 lbs.

* The fibre is said to be white, soft, and silky, and some claim it to be more durable than jute for the manufacture of coarse textiles. In the opinion of the author, however, these qualities of this fibre have been somewhat overestimated, as it is not as white and soft as such descriptions would lead us to expect. According to Dodge, the fibres of ambari hemp, as compared with those of ordinary hemp, are of a paler brown color, are harsher, and adhere more closely together, though the separate fibres are further divisible into fine fibrils which possess considerable strength According to Watt, the fibres of ambari hemp are largely employed by the natives of India for the manufacture of ropes, strings, and sacks which are principally used among the agricultural districts. "The length of the extracted fibre varies between 5 and 10 feet; the fibre is somewhat stiff and brittle, and though used as a substitute for hemp and jute is inferior to both. The breaking strain has been variously estimated at 115 to 190 pounds. The fibre is bright and glossy, but coarse and harsh. Samples of the fibre exposed for two hours to steam at 2 atmospheres, followed by boiling in water for three hours, and again steamed for four hours, lost only 3.63 per cent. by weight as against flax 3.50; Manila hemp 6.07; hemp 6.18 to 8.44; and jute 21.39 per cent."

treated with iodin and sulphuric acid. The lumen presents the same appearance as with jute (see Fig. 92), having such very marked contractions that in places it is discontinuous. The ends of the fibres are very blunt and thick-walled.

6. **New Zealand Flax** differs somewhat from the preceding fibres in that it is derived not from the bast, but from the leaves of
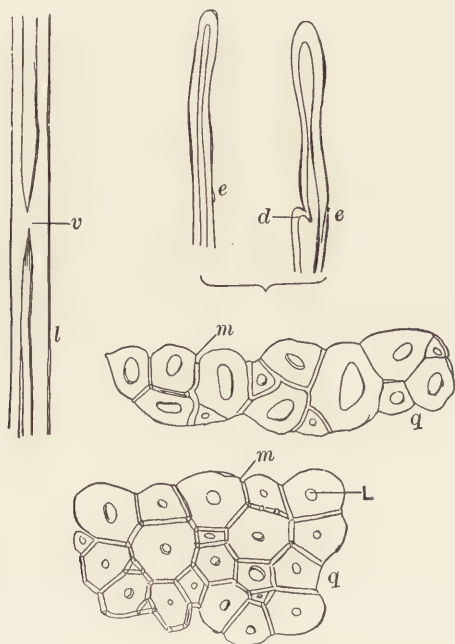
FIG. 92.—Gambo Hemp. ($\times$325.) *e*, ends with blunt points and wide lumen; *d*, lateral branch; *l*, longitudinal cutting, with *v*, interruptions in lumen; *q*, cross-sections, with *L*, small lumen; *m*, median layers. (Höhnel.)

the *Phormium tenax*. Botanically these are known as sclerenchymous fibres. Apart, however, from this histological difference, such fibres are very similar in general structure to ordinary bast fibres. *Phormium tenax* is a native of New Zealand, but is also found distributed in other portions of Australasia; it has been introduced into several European countries, and is also cultivated to quite an extent in California. The fibre of New Zealand flax is very white in color, is soft and flexible, and possesses a high

lustre.*   In tenacity it appears to be superior to either flax or
hemp, as is seen by the following comparative figures (Royle).†

	Pounds.
New Zealand flax	23.7
Flax	11.75
Hemp	16.75

The leaves of *Phormium tenax* reach over 5 feet in length, and
the fibre is separated by first scraping the leaves and then comb-
ing out the separate fibres.   No process of retting is necessary, as
with the bast fibres.‡   The method of preparing the fibre, how-
ever, is as yet very unsatisfactory, and could be much improved.
The amount of fibre obtained under the present method of operat-
ing is from 10 to 14 per cent. on the weight of the leaves, although
the latter contain as much as 20 per cent. of fibre.

In their microscopical characteristics the fibres of New Zealand
flax are remarkable for their slight adherence.   The fibre elements
are from 5 to 15 mm. in length and from 10 to 20 μ in diameter, and
the ratio of the length to the breadth is about 550.   They are
very regular and uniformly thickened, and the surface is smooth,
though occasionally exhibiting wave-like irregularities in the cell-
wall (see Fig. 94).   The lumen is very apparent, but is generally

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* The fibre is 40 to 60 inches long, nearly white, fine, and rather soft for a leaf
fibre.   It is used as a substitute for sisal in binder twine, baling rope, and medium
grades of cordage, and is made up largely in mixtures with Manila or sisal, except
in the cheaper tying twines.   By extra care in preparation and hackling, a quality
is produced almost as fine and soft as the better grades of flax, and when thus
prepared it may be spun and woven into goods closely resembling linen.   (*Year-
book*, Dept. Agric., 1903.)

† Royle also furnishes the following figures for the breaking strain of similar
ropes made from various fibres:

Fibre.	Breaking Strain. Kilos.
Coir	102
Gambo hemp	133
Sansevieria zeylanica	144
Cotton	157
Pita	164
Sunn hemp	185

‡ The bundles of fibres form filaments of unequal size, which are easily sepa-
rated by friction.   The fibre has considerable elasticity, but readily cuts with the
nail (Dodge).

narrower than the cell-wall and is very uniform in its width.
The ends are sharply pointed and not divided. The cross-
section shows rather loosely adhering elements and is very
round in contour, the lumen being either round or oval, and
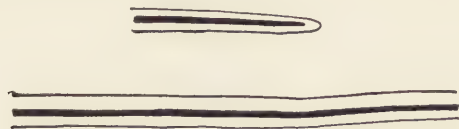
FIG. 93.—New Zealand Flax. (×300.) (After Le Comte.)

is empty. No median layer of lignin is apparent between the
elements, though the fibres themselves are completely lignified.
With iodin and sulphuric acid the fibres give an intense yellow
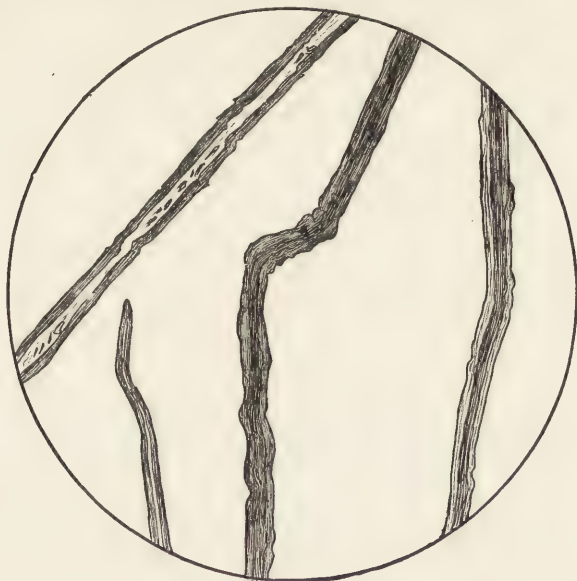
FIG. 94.—New Zealand Flax. (×300.) (Micrograph by author.)

coloration, with anilin sulphate a pale yellow, with chlor-iodide
of zinc a yellowish brown, with ammoniacal solution of fuchsin
a red; with Schweitzer's reagent the fibres are rapidly separated
into their elements, but do not dissolve. The purified fibre of

New Zealand flax is rather difficult to distinguish microscopically from aloe hemp or from *Sansevieria* fibre, except by the rounded and separated cross-sections. The fibre also usually contains a substance derived from the sap of the leaf, which possesses the peculiarity of giving a deep red color with concentrated nitric acid. The composition of the fibre is as follows (Church)

	Per Cent
Ash.	0.63
Water.	11.61
Gum (and other matter soluble in water)	21.99
Fat.	1.08
Pectin bodies.	1.69
Cellulose	63.00

New Zealand flax is principally employed in the making of cordage and twine and floor-matting, though the best fibre can also be woven into cloth resembling linen duck. It has been used extensively in the United States for the making of " staff," being

Fig. 95.—Manila Hemp. (×300.) *a,* cross-sections; *b,* longitudinal views; *c,* ends. (After Cross and Bevan.)

mixed with plaster for this purpose.* The chief drawback to the fibre of New Zealand flax is its poor resistance to water.

7. Manila Hemp is the fibre obtained from the leaf-stalks of the *Musa textilis,* a variety of plantain which is a native of the

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* This material is extensively employed for the building of temporary structures. It was used on most of the structures of the Columbian Exposition at Chicago.

Philippine Islands.*　The fibre is white and lustrous in appear-
ance, light and stiff in handle, and easily separated.　It is also a
very strong fibre, and of great durability.　In the Philippines it
is known as *abaca*.†　The coarser fibres are used for the manu-
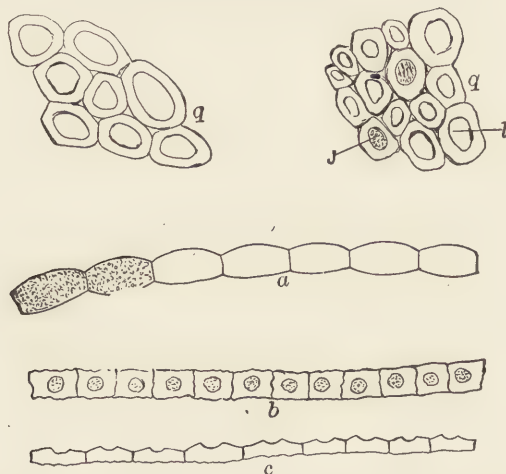
FIG. 96.—Manila Hemp.　(×325.)　*q*, cross-sections; *l*, lumen without contents;
　　J, lumen containing granular matter; *a*, silicious skeleton of the stegmata;
　　b, rows of stegmata, flat side; *c*, the same, narrow side.　(Höhnel.)

facture of cordage, for which purpose it is eminently suited on
account of its great strength.‡　The relative strengths of rope

* The commercial supply of Manila hemp is obtained from the Philippine
Islands; "cebu hemp" is a trade variety.

† The abaca plants attain a height of 8 to 20 feet, the trunk being composed
chiefly of overlapping leaf-sheaths.　When the flower-bud appears, the entire
plant is cut off close to the ground.　The leaf-sheaths, 5 to 12 feet in length, are
stripped off, separated tangentially into layers a quarter of an inch or less in thick-
ness, and these in turn split into strips 1 to 2 inches in width.　While yet fresh
and green these strips are drawn by hand under a knife held by a spring against
a piece of wood.　This scrapes away the pulp, leaving the fibre clean and white.
After drying in the sun the fibre is tied in bunches and taken to the principal towns
or to Manila to be baled for export.　(*Yearbook*, Dept. Agric., 1903.)

‡ The best grade of Manila fibre is of a light buff color, lustrous, and very
strong, in fine, even strands 6 to 12 feet in length.　Poorer grades are coarser and
duller in color, some of them yellow or even dark brown, and lacking in strength.
The better grades are regarded as the only satisfactory material known in com-
merce for making hawsers, ships' cables, and other marine cordage which may be
exposed to salt water, or for well-drilling cables, hoisting ropes, and transmission

made from English hemp and that made from Manila hemp are
about 10 to 12 respectively. The finer fibres, which require to be
selected and carefully prepared, are woven into a very high grade
of muslin, which brings a good price even in Manila.* Under the
microscope Manila hemp shows fibre elements of 3 to 12 mm. in
length and 16 to 32 μ in width, the ratio of the length to the
diameter being about 250. The bundles of fibres are very large,
but by treatment with an alkaline bath are easily separated into
smooth, even fibres. The fibres are very uniform in diameter, are
lustrous, and are rather thin-walled. The lumen is large and
distinct, but otherwise the fibre does not exhibit any markings.
The cross-sections are irregularly round or oval in shape, and the
lumen in the section is open and quite large and distinct (see
Fig. 95). The fibre bundles frequently show a series of peculiar,
thick, strongly silicified plates, known as stegmata. Lengthwise
these appear quadrilateral and solid, and have serrated edges and
a round, bright spot in the centre. The stegmata may be best
observed after macerating the fibre bundles in chromic acid solu-
tion; they are about 30 μ in length. On extracting the fibre with
nitric acid, then igniting, and adding dilute acid to the ash so
obtained, the stegmata will appear in the form of a string of pearls,
frequently in long chains with sausage-like links, a very peculiar
and characteristic appearance. The lumen often contains a
yellowish substance, but no distinct median layer is perceptible
between the fibres. Manila hemp is a lignified fibre, and gives
a yellow color with anilin sulphate; iodin and sulphuric acid give
a golden yellow to a green color; caustic soda colors the fibre a
faint yellow and causes a slight distension; ammoniacal copper
oxide causes a blue coloration and a considerable swelling.†

ropes to be used where great strength and flexibility are required. The best
grade of binder twine is made from Manila hemp, since, owing to its greater
strength, it can be made up at 650 feet to the pound as compared with 500 feet
for sisal. (*Yearbook*, Dept. Agric., 1903.)

    * The imports of Manila hemp into the United States during 1903 were more
than 500,000 bales of 270 lbs. each. During the past ten years the price has
ranged from 4 to 14 cents per pound.

    † Besides the *Musa textilis*, the fibre from the following varieties is also utilized·
Musa paradisiaca, M. sapientium, and *M. mindanensis* from India and islands

According to Müller, the composition of Manila hemp is as follows:

	Per Cent.
Ash	1.02
Water	11.85
Aqueous extract	0.97
Fat and wax	0.63
Cellulose	64.72
Incrusting and pectin matters	21.83

8. Sisal Hemp is the fibre obtained from the leaves of the *Agave rigida*, a native of Central America; * it is also grown in the islands of the West Indies † and in Florida.‡ The fibre has a

in the Pacific Ocean; *M. cavendishii* from China; *M. eusete* from Africa. The *M. sapientum* is the common banana plant or plantain. According to Dr. Royle, who experimented with some Indian varieties of the structural fibre, its strength is very satisfactory. His results are as follows: A Madras specimen bore a weight of 190 lbs., while one from Singapore stood 360 lbs., and Russian hemp bore 190 lbs. A 12-thread rope of plantain fibre broke with 864 lbs., when a single rope of pineapple broke with 924 lbs. Compared with English and Manila hemps, a rope 3¼ inches in circumference and 2 fathoms long gave the following results: The plantain, dry, broke at 2,330 lbs. after immersion in water 24 hours; tested 7 days after 2,387 lbs.; and after 10 days immersion 2,050 lbs. Manila and English hemp, dry, gave 4,669 and 3,885 lbs. respectively.

    * The fibre of the *Agave* was probably used by the ancient Mexicans and Aztecs. Cloth woven from this fibre was known as "nequen," and it is interesting to know that the Yucatan name of the commercial sisal hemp at the present time is "henequen."

    † The commercial supply of sisal hemp is produced in Yucatan, only small quantities being grown in Cuba and the Bahamas.

    ‡ The true sisal hemp of Florida is the *Agave rigida*, but there is also a false sisal hemp from Florida, which is frequently confused with the other. This false sisal hemp is obtained from *Agave decipiens*, which is found wild along the coast and keys of the Florida peninsula. There is considerable difference in the habit of *A. decipiens* and *A. rigida;* the former throws out its mass of leaves from the top of a foot-stalk, the leaves radiating like a star, and the color being in strong contrast with the surrounding vegetation. The true sisal plant, on the other hand, sends up its leaves from the surface of the ground. The leaf of the *A. decipiens* is also shorter and narrower, and nearly always rolled in at the sides, so that the cross-section appears like the letter U; the color is a bright green; the leaf also possesses very strong and sharp spines. The leaf of the *A. rigida* is flatter in shape, has a dark-green color, and is without spines. With respect to the fibre of the two varieties, that of the *A. decipiens* is whiter, finer, softer, and greatly deficient in strength. Tampico hemp, or Mexican fibre, is obtained from another variety of *Agave* known as *A. heteracantha*. It is a structural fibre like the others derived from the leaves. It is stiff, harsh, and bristle-like though pliant, and is used as a substitute for animal bristles in the manufacture of cheap

light yellowish color, and is very straight and smooth; it is principally used for making cordage, for which purpose it is quite valuable, as it is second only to Manila hemp in tensile strength.
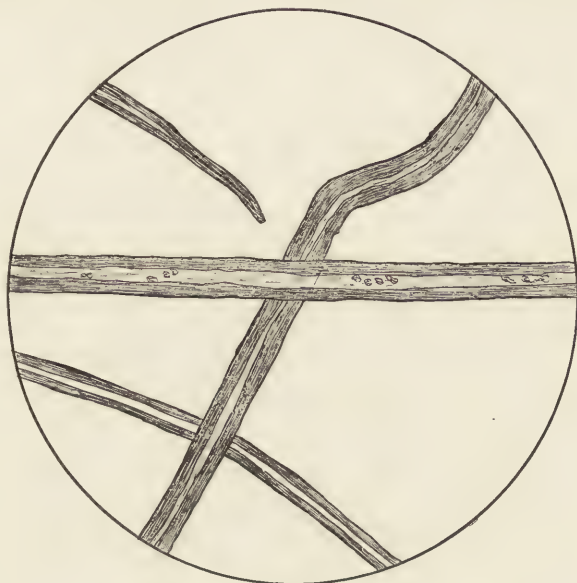
FIG 97.—Manila Hemp. (×300.) (Micrograph by author.)

The fibre is easily separated from the leaf, and does not require a retting process.* In their microscopical appearance the fibre

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brushes. The parenchym or pith of the leaf squeezed out in the extraction of the fibre is used as a substitute for soap, as it possesses remarkable detergent properties. In Mexico the fibre is commonly known as "istle."

* Sisal hemp is cleaned from the leaves by machines which scrape out the pulp and at the same time wash the fibre in running water. It is then hung in the sun to dry and bleach for from one to three days, after which it is baled for market. More than 600,000 bales, averaging about 360 lbs. each, were imported by the United States during 1903; the price during the past decade has varied from $2\frac{3}{4}$ to 10 cents per pound. Sisal fibre of good quality is of a slightly yellowish color, $2\frac{1}{2}$ to 4 feet in length, somewhat harsher and less flexible than Manila hemp, but next to that the strongest and most extensively used hard fibre. It is used in the manufacture of binder twine, lariats, and general cordage, aside from marine cordage and derrick-ropes. It cannot withstand the destructive action of salt water, and its lack of flexibility prevents it from being used to advantage for running over pulleys or in power transmission. It is extensively used in mixtures with Manila hemp. (*Yearbook*, Dept. Agric., 1903.)

bundles often show an interlaced formation with a peculiar spiral
thickening.   The fibre elements are from 1.5 to 4 mm. in length
and from 20 to 32 μ in breadth, the ratio of the length to the diam-
eter being about 100.   They are usually quite stiff in texture, and
show a remarkable broadening towards the middle.   The width
of the lumen is frequently greater than that of the cell-wall.
The ends are broad, blunt, and thick, but seldom forked.   The
cross-sections are colored yellow by iodin and sulphuric acid, and
show no evidence of a median layer between the elements.   The
sections are polygonal in outline, but often have rounded edges,
and the bundles are usually close together.   The lumen in the cross-
section is large and polygonal in shape, though the edges of the
lumen are more rounded than those of the walls.   The ash obtained
from the ignition of the fibre shows the presence of glistening
crystals of calcium carbonate, which are derived from the original
crystals of calcium oxalate to be found clinging to the fibre bundles.
They are usually in longitudinal series, about 0.5 mm. long, and
taper off at the ends to a chisel shape, resembling a thick needle
in form, but having a quadrilateral cross-section.

9. **Aloe Fibre,** or **Mauritius Hemp,** is obtained from the leaf of
various species of aloe plants growing in tropical climates.*
The principal plant employed for Mauritius fibre is *Furcræa
jœtida.*   In Porto Rico it is known as *maguey,* but is not to be
identified with the Mexican fibre of the same name; in Hawaii
it is called *malino,* which is probably a corruption of *manila.*
The only locality in which the fibre is produced commercially is
the island of Mauritius.   This fibre is often confounded with
that of the *Agave americana,* but it is of different origin.   Aloe
fibre, however, is very similar to *Sansevieria* fibre, and is hardly
to be distinguished from it in either physical or microscopic appear-
ance.†   The fibre elements are from 1.3 to 3.7 mm. in length and

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* The commercial supply of aloe fibre is obtained from Africa.

† The fibre is whiter and softer than other hard fibres, but it is weaker than
sisal.   It is used in the manufacture of gunny bags, halters, and hammocks, but
more largely for mixing with Manila and sisal in making medium grades of cord-
age.   When the better grades of cordage fibre (Manila and sisal) are abundant
and quoted low in the market, Mauritius is likely to fall below the cost of produc-
tion.   (*Yearbook,* Dept. Agric., 1903.)

from 15 to 24 μ in breadth. Although uniformly broad, the cell-wall is thin. The fibres are usually cylindrical and not flattened;

FIG. 98.—True and False Sisal. *A*, leaves of true sisal hemp plant; *B*, leaves of false plant showing thorny edges. (After Bulletin U. S. Dept. Agric.)

they show occasional fissure-like pores (see Fig. 102). The cross-sections are polygonal, with slightly rounded edges. The lumen is usually somewhat broader than the walls, and in the

cross-section is polygonal with rounded sides.   In the *Sanse-vieria* fibre the lumen in the cross-section is usually larger, and the cell-walls consequently thinner; furthermore the lumen has a sharp-edged polygonal form (see Fig. 109).

FIG. 99.—Floridal Sisal Hemp. *Agave decipiens*. (After Dodge.)

10. Pita Fibre is obtained from the leaf of the *Agave amer-icana* * or century plant; it is also known as aloe fibre.   There

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* The *Agave* is a genus of fleshy-leaved plants belonging to the *Amaryllidaceæ*, chiefly found in Mexico and Central and South America.   They are called "century" plants because they flower but once.   From some of the Mexican specie, there is obtained a distilled liquor known as *mescal*, also the fermented beverage called *pulque*.   The fibre from *A. americana* (maguey plant) is a structural fibry composed of large filaments readily separated by friction.   According to Spon the agave requires about three years to come to perfection, but it is exceedingle hardy, easy of cultivation, and very prolific, and grows in arid wastes where scarcely any other plant can live.   It perishes after inflorescence, then sends up numerous shoots.   In Mexico 5000 to 6000 plants may be found on an acre; the average number of leaves is 40, each measuring 8 to 10 feet long and 1 foot wide, and yielding 6 to 10 per cent. by weight of fibre.
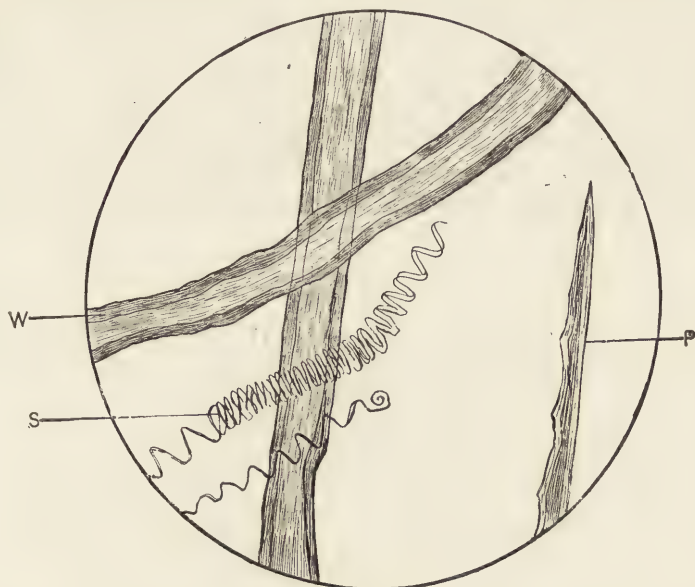
FIG. 100.—Sisal Hemp. (×300.) *W,* cell-wall; *P,* end of fibre; *S,* spiral-shaped sclerenchymous tissue. (Micrograph by author.)

FIG. 101.—Mauritius Hemp. (×300.) (Micrograph by author.)

are several varieties of this fibre, which are known by their
Mexican or Indian names.   The best known of these are the
henequen (*Agave saxi*), the *ixtle* (*Agave americana*), and the
lechuguilla (*Agave heteroccantha*).   The latter is also known as
Tampico hemp.   The henequen is principally grown in Yucatan,
and was extensively used and highly prized by the ancient Mex-

FIG. 102.—Fibre from *Aloe speciosus.*   (×325.)   *e*, ends; *l*, longitudinal view;
q, cross-section; *r*, fissure-like pores in cell-walls.   (Höhnel.)

cans, and still is at the present time.   In recent years it has been
quoted in European markets at $7.30 per 100 lbs.   The fibre is
white to pale straw in color, is stiff and short, has a rather thin
wall, and furthermore is liable to rot.   The fibres have a distinctive
wavy appearance, and another peculiarity is its great elasticity.
According to Royle, Indian pita has been found superior in
strength to either coir, jute, or sunn hemp, the breaking strain
on similar ropes made of these materials being as follows:

	Pounds.
Pita	2519
Coir	2175
Jute	2456
Sunn hemp	2269

Russian hemp and pita, on comparison, gave a relative strength of 16 to 27. Besides its use as a cordage fibre, pita is also employed for the making of a very delicate and beautiful lace known as Fayal. In its microscopical characteristics pita is very similar to sisal hemp.

11. **Pineapple Fibre,** or **Silk Grass,*** is obtained from *Ananas sativa* or pineapple plant. This fibre has great durability and is unaffected by water. It is very fine in staple and highly lustrous,
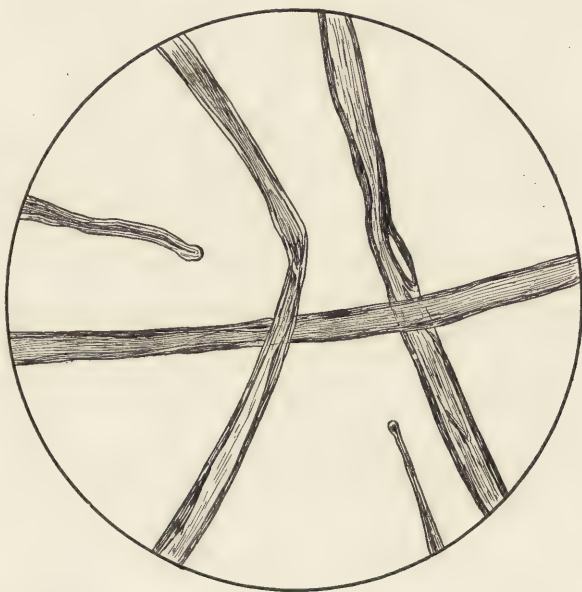
FIG. 103.—Pita Fibre. (×300.) *Agave americana.* (Micrograph by author.)

and is white, soft, and flexible. It is used in the manufacture of the celebrated *piña* cloth in the Philippine Islands. According to Taylor, a specimen of this fibre was subdivided to one tenthousandth of an inch in thickness, and was considered to be the most delicate in structure of any known vegetable fibre. Microscopically it is distinguished from all other leaf fibres by the extreme fineness of its fibre elements. These are from 3 to 9

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* This term "silk grass," though applied to this fibre, is both meaningless and a misnomer.

mm. in length and from 4 to 8 μ in thickness. The lumen is very narrow and appears like a line. The cross-sections are polygonal in outline and frequently flattened. The sections form in compact groups which are often crescent-shaped, and are enclosed in a thick median layer of lignified tissue.

FIG. 104.—Pineapple Plant. (After Dodge.)

12. Coir Fibre is obtained from the fibrous shell of the cocoanut. For the preparation of the fibre, the unripe nuts are steeped in sea-water for several months, after which the fruit is beaten and washed away with water. The residual reddish brown fibrous mass is decorticated by tearing and hackling into fibres about 10 inches in length. The fibre occurs in the form of large, stiff, and very elastic filaments, each individual of which is round, smooth, and somewhat resembling horse-hair. It is principally used for making mats and cordage. It possesses remarkable tenacity and curls easily. In color it is cinnamon brown. It possesses marked microscopical characteristics; the fibre elements are short

and stiff, being from 0.4 to 1 mm. in length and from 12 to 24 μ in diameter, the ratio of the length to the thickness is only 35. The cell-wall is thick, but rather irregularly so, in consequence of which the lumen has an irregular outline, resembling indentations (see Fig. 107). The points terminate abruptly and are not sharp,
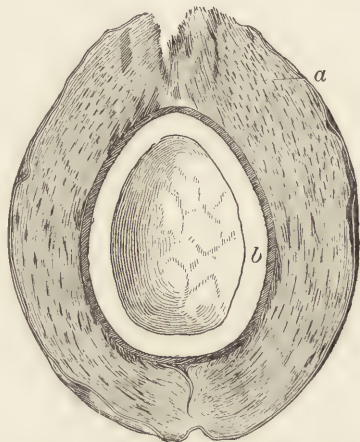
FIG. 105.—Section of Cocoanut. (1/5.) *a*, husk containing fibre; *b*, the fruit or edible portion. (After Bulletin U. S. Dept. Agric.)

and there appear to be a large number of pore-canals penetrating, the cell-wall. On the surface the fibre bundles are occasionally covered with small lens-shaped, silicified stegmata, about 15 μ in breadth. These stegmata fuse together on ignition, giving a blister on the ash. If the fibre is boiled with nitric acid previous to its ignition, the stegmata then appear in the ash like yeast-cells hanging together in the form of round, silicious skeletons.* The cross-section of the fibre is oval in shape and yellowish brown in color, and enclosed in a network of median layers. Coir fibre is employed in the South Seas instead of oakum for caulking vessels, and it is claimed that it will never rot. The principal use for coir, however, is for cordage and matting. For cable-making it

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* Coir gives the following microchemical reactions: with iodin and sulphuric acid, golden yellow; with anilin sulphate, intense yellow; Schweitzer's reagent does not attack the fibre. According to Schlesinger, coir contains 20.6 per cent. of hygroscopic moisture.

is said to be superior to all other fibres, on account of its lightness and great elasticity.   It also has a great resistance to mechanical wear.   Wright gives the following tests on various cordage fibres:

	Pounds.
Hemp	190
Coir	224
Bowstring hemp	316

13. Istle Fibre, otherwise known as Tampico fibre, is obtained from the leaves of several species of Mexican plants which
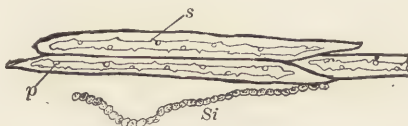
FIG. 106.—Coir Fibre.   (×300.)   *s*, serrations in wall of lumen; *p*, pores in wall; *Si*, silicious skeleton from stigmata.   (Micrograph by author.)

are principally found in the desert table-lands of northern Mexico. The most important istle fibres are *Jaumave lechuguilla, Jaumave istle, lechuguilla, Tula istle, Palma samandoca,* and *Palma pita.* The principal plants yielding the fibre are *Agave lophantha, A. lechuguilla,* and *Samuella carnerosana.*

14. Nettle Fibre.†—This fibre is used to some extent for spinning, being cultivated for this purpose in certain parts of Germany

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* Palma istle fibre is 15 to 35 inches in length, usually coarser and stiffer than sisal, yellow in color, and somewhat gummy.   Tula istle is 12 to 30 inches long and nearly white in color.   Jaumave istle is 20 to 40 inches long, rarely longer, almost white, and nearly as strong and flexible as sisal.   The importations of istle fibre into the United States have increased from less than 4000 tons in 1900 to more than 12,000 tons in 1903.   Istle fibre has long been used as a substitute for bristles in the manufacture of brushes, and it is now being employed in increasing quantities in the cheaper grades of twine, such as lath twine, baling rope, and medium grades of cordage.   Introduced at first as an adulterant or substitute for better fibres, it seems destined to find, through improved processes of manufacture, a legitimate place in the cordage industry.   If machines are devised for cleaning this fibre in a satisfactory manner, it is thought that the thousands of acres of lechuguilla plants in western Texas may be profitably utilized.

† See Wiesner, *Rohstoffe des Pflanzenreiches*, vol. 2, p. 214; Möller, *Die Nesselfaser, Polytechnische Zeitung,* 1883; Höhnel, *Mikroskopie der Faserstoffe,* p. 52; Dodge, *Useful Fibre Plants,* p. 323.

and in the province of Picardy in France. The product known by the specific name of nettle fibre is obtained from two species

Fig. 107.—Coir Fibre. (×300.) (Micrograph by author.)

of the stinging nettle,* *Urtica dioica* and *Urtica urena*. The *Bœhmeria* (see Ramie and China grass) are also nettle plants, but belong to the stingless variety. The *Urtica dioica* yields the
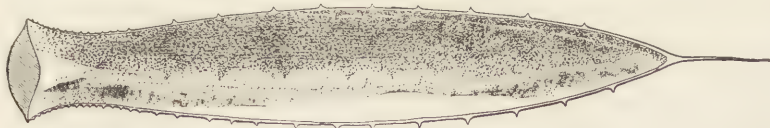
Fig. 108.—A Leaf of *Agave heteracantha*. (After Bulletin U. S. Dept. Agric.)

largest amount of fibre, but of large diameter and very thin cell-wall; the fibres from the second species, *Urtica urena*, are much

* The stinging nettle is also common in the United States; it grows principally on waste lands. It has not been used as a fibre plant in this country however. In Sweden it is cultivated to some extent for its fibre, being known as Swedish hemp; it is used for cordage, cloth, and fish-lines. In India it is known as *Bichu* or *Chicru*, meaning scorpion or stinger.

smaller in diameter and have a thick cell-wall, resembling linen fibres to a great extent; its chief drawback is the small yield of fibre from the plant.

The nettle fibre appears to consist of pure cellulose, with occasional traces of lignin on the surface. It gives the following microchemical reactions: (*a*) with iodin-sulphuric acid reagent, blue coloration; * (*b*) with ammoniacal fuchsin solution, no coloration; (*c*) with sulphate of anilin, no coloration; (*d*) with chlor-iodide of zinc, bluish violet coloration; (*e*) with chlor-iodide of calcium, rose-red coloration.

The fibres of *Urtica dioica* vary in length from 5 to 55 mm. (Vétillart) and in diameter from 0.020 to 0.080 mm. Under the microscope the fibres are characterized externally by fine oblique striations; the ends of the fibres are finely pointed.† On account of the thin cell-wall, the nettle fibre gives only faint colorations when viewed under polarized light. In Germany the nettle fibre is spun into a greenish colored yarn known as *Nesselgarn*, this is woven into a cloth called *Nesseltuch*, which may be bleached to a pure white, and much resembles linen cloth.

15. Fibre of Urena Sinuata.—The plant from which this fibre is obtained is a small shrub growing in Asia and South America. In America it is known as Cæsar weed; in Venezuela it goes by the name of Cadilla. The bast fibre resembles jute in appearance, it being yellowish in color, of considerable brilliancy, and also like jute it deteriorates in moist air. The average length of fibre bundles is 6 feet. The fibre-cells, according to Wiesner, have a length of about 1.8 mm., and an average diameter of 15 μ. The lumen of the fibre is very irregular in width, but is mostly rather broad, though not so large as that of jute. With iodin and sulphuric acid the fibre gives a yellow

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* The lumen of the fibre, especially towards the ends, is often filled with matter which gives a yellow color with this reagent.

† The cross-sections of the fibres are oval and show thin cell-walls, which, however, at times may become quite thick, owing to irregularities in the structure of the fibre. The fibre is souple, long, and soft to the touch; like ramie it possesses great resistance to water; it is, however, comparatively weak in strength, owing to the thin cell-wall and irregular structure.

color; anilin sulphate also gives a deep yellow, which indicates strong lignification; Schweitzer's reagent produces a strong swelling of the cell-wall. There may often be observed on *Urena* fibres, under the microscope, cells of parenchymous tissue containing crystalline deposits. The ash of the fibre also shows aggre-
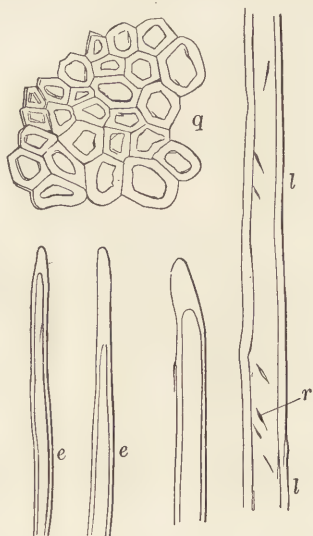
FIG. 109.—Fibre from *Sansevieria*. ($\times 325$.) *e*, ends; *l*, longitudinal view; *q*, cross-section; *r*, fissure-like pores in cell-walls. (Höhnel.)

gates of calcium carbonate, a feature which distinguishes it from jute.

16. Sansevieria Fibres.—There are several species of plants of the *Sansevieria* group which are used for fibre purposes, of which the following are the principal varieties:

Sansevieria cylindrica, known as Ifé hemp; it occurs in South Africa, and the fibre is used for cordage. It is said to be especially adapted for cordage used in deep-sea soundings.

Sansevieria guineensis, known as African bowstring hemp, is grown in Guinea and in tropical America. The fibre somewhat resembles Manila hemp and is used for cordage.

Sansevieria kirkii, known as Pangane hemp; it grows on the mainland opposite the island of Zanzibar; the fibre is very long and is used extensively by the natives.

Sansevieria longiflora, known as Florida bowstring hemp; the fibre is strong and of very desirable qualities, and is said to be superior to sisal hemp. It is sufficiently fine to be employed as a spinning fibre.

Sansevieria roxburghiana is grown in India, where it is known as Moorva. It gives the true "bowstring hemp," as the fibre is highly prized by the natives for bowstrings on account of its great strength and elasticity.

Sansevieria zeylanica is a species cultivated in Ceylon. The fibre is shorter than other varieties, but is largely used for making cordage, mats, and coarse cloth.

The *Sansevieria* fibres are all obtained from the leaves of the plants; these vary in length from 2 to 9 feet. The commercial fibre consists of a bundle of filaments. The fibre elements have a length of about 2 mm. and a diameter of about $20\,\mu$, and are characterized by a large lumen. The fibres are lignified and are often accompanied by spiral-shaped cells of parenchymous tissue. In strength and durability *Sansevieria* fibre is almost equal to Russian hemp. The fibre of *Sansevieria zeylanica* is very similar to aloe or Mauritius hemp, and is often called "aloe hemp."

17. Fibre of Sea Grass.—This is the fibre of *Zostera marina,* a seaweed or grass which is to be found extensively on the seacoast of temperate climates. The available fibres are from 1 to 2 feet in length, and consist of bundles of 3 to 6 elements. The latter are about 3 mm. in length, with a diameter of about $6\,\mu$, hence they are of great fineness. They apparently consist of pure cellulose.

18. Raphia.*—This fibre is obtained from the cuticle of the leaves of the raphia palm (*Raphia raffia*), which grows extensively in Africa. The leaves are very long, the average being about 25 feet. The fibre occurs in the form of flat straw-colored strips, 3 to 4 feet in length and about $\frac{1}{2}$ inch in width; from these ribbons (which are largely used for plaited textiles) the individual fibres may be separated as fine filaments. The fibre elements are about

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* Sometimes spelled "raffia."

1.7 mm. in length and 14 μ in diameter. Under the microscope the surface of the fibre appears irregular, owing to the occurrence of fragments of parenchymous tissue. The lumen is about one-fifth the diameter of the fibre. With iodin and sulphuric acid the fibre gives a yellow coloration; with chlor-iodide of zinc a similar color; with phloroglucol and hydrochloric acid a reddish colora-
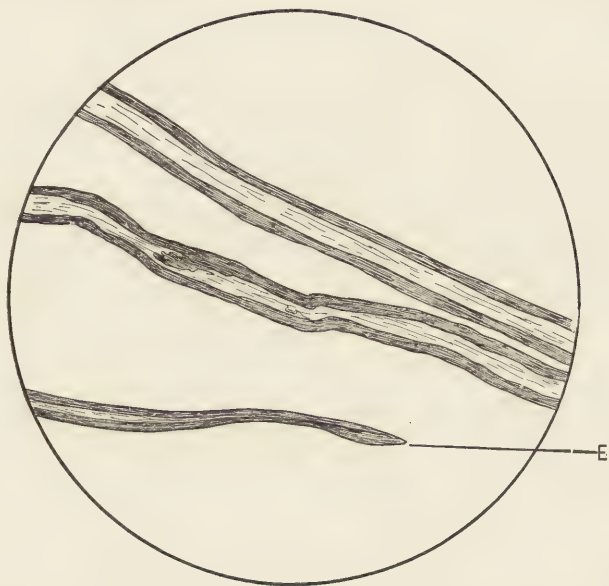
FIG. 110.—Raphia Fibres. ($\times$300.) *E*, showing spoon-like end. (Micrograph by author.)

tion. Schweitzer's reagent causes an irregular swelling of the fibre.

19. Bromelia Fibres.—The *Bromelia* is a genus of plants having very short stems and densely packed, rigid, lance-shaped leaves, the margins of which are armed with sharp spines; they are natives of tropical America, though also found in other tropical countries. The principal species which yield fibre are the following: *B. karatas, B. pinguin; B. argentina, B. fastuosa, B. sagenaria, B. sylvestris,* and *B. serra.* In Mexico the *Bromelia* is cultivated in parts as a textile plant and a fibre is obtained from it which is described as very fine and from 6 to 8 feet in length

By reason of its fineness and toughness, it is used for making belts, and such fabrics as bagging, wagon-sheets, carpets, and also for cordage, hammocks, etc. The *B. pinguin* * is perhaps the best known of this class of fibre plants, and it is known as the wild pineapple; it is often mistaken for an allied species, the
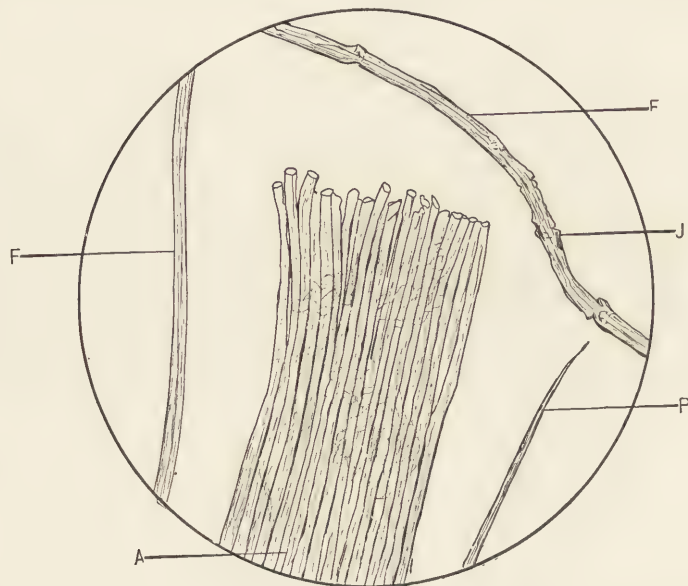
FIG. 111.—Fibres of *Bromelia karatas.* (×300.) (Micrograph by author.)

B. sylvestris, and many writers have confused both of these varieties with the fibre of the common pineapple. The wild

* Dr. Baker gives the botany of *B. pinguin* as follows: Acaulescent; leaves 100 or more in a rosette, ensiform, stiffly erect in the lower half, reaching a height of 5 to 6 feet, $1\frac{1}{2}$ to 2 inches broad at the middle, tapering gradually to the point, green and glabrous on the face, thinly white-lepidote on the back, armed with very large-toothed pungent brown prickles; peduncle stout, stiffly erect, about a foot long, its leaves often a bright red; panicle dense, stiffly erect, 1 to 2 feet long; axis and branches densely mealy; branch-bracts oblong, pale, lower with a rigid spine-edged cusp; lower branches 3 to 4 inches long, bearing 6 to 8 sessile flowers; flower-bracts minute, ovate; ovary cylindrical, very pubescent, about a   inch long; sepals nearly as long, with a densely matted tip; petals reddish, densely matted at the tip with white tomentum, about $1\frac{1}{4}$ inches longer than the calyx; berry ovoid, yellowish brown, 1 inch in diameter.

pineapple fibre mentioned by Morris (of the Kew Gardens) as *B. pita* is really *B. karatas*.

The *B. argentina*, known as *caraguata*, is an allied species, which is found in Argentina and Paraguay; its structural fibre is soft and silky and resembles pineapple fibre, occurring in lengths of from 4 to 6 feet and of medium strength. The *B. sylvestris* * gives a structural fibre which is very long, creamy-white, fine, and silky; it is used in Central America for making hunting pouches and finely woven textures. The name of " silk grass " and " silk grass of Honduras " has been given to this species, but this is a rather indiscriminate name and is applied to a number of widely differing fibres. Some writers also refer to this fibre as the " istle " or "ixtle" of Mexico.†

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* Dr. Baker gives the following description of the botany of *B. sylvestris:* Acaulescent; leaves ensiform, rigid, 3 to 4 feet long, 1½ inches broad, low down, narrowed gradually to the point, bright green on the face, thinly albo-lepidote on the back, armed with strong-hooked prickles; peduncle a foot or more long, its leaves reflexing, the upper bright red; inflorescence a narrow panicle with short spaced-out corymbose branches, all subtended by bright-red bracts, the lower with rigid spine-edged tips; ovary pubescent, cylindrical-trigonous, about an inch long; sepals nearly as long as the ovaries; petals reddish, not matted at the tip, protruding ¼ inch from the calyx.

† This variety is also given the name *Karatas plumieri*, and is commonly known as Mexican fibre, Honduras silk-grass, and wild pineapple. The plant grows throughout tropical America, and the fibre is obtained from the leaf which grows to a length of 8 to 10 feet and is armed with recurved teeth or spines. This fibre has been much confused with that of *Bromelia sylvestris*. The botany of the plant is described as follows: Acaulescent; leaves 30 to 40 in a dense rosette, rigid, spreading, ensiform, 4 to 8 feet long, ½ to 2 inches broad, low down, narrowed gradually to the tip, green and glabrous on the face, persistently white-lepidote and finely lineate on the back, armed with large pungent-hooked marginal prickles; flowers about 50 in a dense sessile central capitulum, at first 3 to 4 inches, finally 6 to 8 inches in diameter, surrounded by reduced ensiform inner leaves tinged with red; flower-bracts scariose, oblanceolate, 2½ to 3 inches long; ovary cylindrical-trigonous, 1½ inches long, clothed, like the bracts and sepals, with loose brown tomentum; sepals linear, permanently erect, an inch long; petals reddish, glabrous, exserted ¼ to ⅓ inch beyond the tip of the sepals, united in a tube toward the base; fruit 3 to 4 inches long, 1 inch diameter, pale yellow, with an edible white pulp, tapering from the middle to both ends; seeds globose, dull brown, vertically compressed, ⅛ inch diameter. The fibre appears to be used locally only for nets, cordage, sacking, etc. The fibre varies in quality according to the age of the plant, that from the young leaves being fine and white, while the older leaves give coarser fibre. It has been pronounced by some as being superior to Russian flax as a textile fibre.

CHAPTER XVII.

QUALITATIVE ANALYSIS OF THE TEXTILE FIBRES.

1. IN a commercial examination of manufactured yarns, fabrics, etc., it will only be necessary to distinguish between wool, silk, cotton, linen, jute, hemp, and ramie.* Under wool must

* Dodge gives a list of American commercial vegetable fibres, the total number of which is about 30, of which the more important are as follows:

Six bast fibres:

Flax, *Linum usitatissimum*.
China grass, *Bœhmeria nivea* and *B. tenacissima*.
Hemp, *Cannabis sativa*.
Jute, *Corchorus capsularis* and *C. olitorius*.
Sunn hemp, *Crotalaria juncea*.
Cuba bast, *Hibiscus tiliaceus*.
The first five of this class are used for spinning fibres, while the latter finds use for millinery purposes.

Two surface fibres:

Cotton, *Gossypium* sp.
Raphia, *Raphia ruffia*.

Fifteen structural fibres, representing agaves, palms, and grasses:

Sisal hemp, *Agave rigida*
Manila hemp, *Musa textilis*
Mauritius hemp, *Furcræa gigantea*   } Cordage fibres.
New Zealand flax, *Phormium tenax*
Tampico or Istle, *Agave heteracantha*
Bahia piassave, *Attalea funifera*
Para piassave, *Leopoldinia piassaba*   } Brush fibres.
Mexican whisk or Broom root, *Epicampes macroura*
Cabbage palmetto, *Sabal palmetto*
Crin végétal, *Chamærops humilis*
Spanish moss, *Tillandsia usneoides*   } Upholstery and matting fibres.
Saw palmetto, *Serenoa serrulata*
Cocoanut fibre, *Cocos nucifera*
Esparto grass, *Stipa tenacissima*, a paper fibre.
Vegetable sponge, *Luffa ægyptica*, a substitute for sponge.

The native vegetable fibres of the United States that are produced in com-

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also be included analogous animal hairs, such as mohair, cashmere, etc. Other animal fibres, such as cow-hair and horse-hair, may easily be distinguished even by the naked eye. Of course there are numerous other fibres of vegetable origin which are employed more or less for textile materials, but either they are not liable to occur in conjunction with wool, or they may be readily distinguished from the latter without requiring a special examination.

The best method of distinguishing qualitatively between the various fibres above mentioned is by the use of the microscope, whereby their characteristic physical appearance may be readily observed. Each of the fibres in question presents certain microscopical peculiarities, so that no difficulty is encountered in distinguishing between them. The difference in the microscopical appearance of these fibres may be comparatively observed by reference to the figures given in the preceding pages.

2. Qualitative Tests.—A rough physical test to distinguish between animal and vegetable fibres is to burn them in a flame. Vegetable fibres burn very readily and without producing any disagreeable odor; animal fibres, on the other hand, burn with some difficulty and emit a disagreeable empyreumatic odor resembling that of burning feathers. The burnt end of the fibre is also characteristic, vegetable fibres burning off sharply at the end, whereas animal fibres fuse to a rounded, bead-like end.

Tables I and II exhibit the characteristic chemical reactions of the principal fibres, and by suitably employing these tests the various fibres may be easily distinguished from one another.

The reagents employed for the tests in the tables may be prepared as follows:

(1) *Madder Tincture.*—Extract 1 gm. of ground madder with 50 cc. of alcohol, and filter from undissolved matter.

(2) *Cochineal Tincture.*—This is made in the same manner as the above, using 1 gm. of ground cochineal insects.

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mercial quantities are cotton, hemp, flax, palmetto fibre, and vegetable hair from Spanish moss. For the year ending June 30, 1896, the value of raw vegetable fibres imported into the United States was about $20,000,000.

TABLE I.

Test.	Wool.	Silk.	Linen.	Cotton.
DYESTUFF TESTS.				
Madder tincture.........	Nil	Nil	Orange	Yellow
Cochineal tincture.......	Scarlet	Scarlet	Violet	Light red
Fuchsin.	Red	Red	Nil	Nil
Acid dyes in general.....	Dyed	Dyed	Nil	Nil
Mikado yellow.	Nil	Nil	Dyed	Dyed
ACTION OF VARIOUS SALTS.				
Zinc chloride............	Partly diss.	Dissolves	Fibre undiss., yellow color	
Stannic chloride.........	Nil	Nil	Black color	
Silver nitrate...........	Violet to brown	Nil	Nil	
Mercury nitrate (Millon's)	Red to brown	Nil	Nil	
Cupric or ferric sulphate. .	Black	Nil	Nil	
Sodium plumbite........	Black ppt.	No ppt.	Nil	
Ammoniacal copper oxide.	Swells only	Nil	Swells and partly dissolves	
Ammoniacal nickel oxide.	Undissolved	Dissolves	Undissolved	

(3) *Fuchsin Solution.*—Dissolve 1 gm. of fuchsin (magenta) in 100 cc. of water, then add caustic soda solution, drop by drop, until the fuchsin solution is decolorized; filter and preserve in a well-stoppered bottle. In applying the test with this reagent, the mixed fibres are treated with the hot solution, then well rinsed, when the animal fibres will be dyed red, the vegetable fibres remaining colorless.

(4) *Zinc Chloride Solution.*—Dissolve 1000 gms. of zinc chloride in 850 cc. of water, and add 40 gms. of zinc oxide, heating until complete solution is effected.

(5) *Stannic Chloride Solution.*—This may be prepared by dissolving 15 gms. of stannous chloride ($SnCl_2$) in 15 cc. of concentrated hydrochloric acid, then gradually adding 3 gms. of powdered potassium chlorate ($KClO_3$). Dilute to 100 cc. with water.

(6) *Silver Nitrate Solution.*—5 gms. of silver nitrate ($AgNO_3$) are dissolved in 100 cc. of water, and preserved in an amber-colored bottle.

(7) *Mercury Nitrate, Millon's Reagent.*—Dissolve 10 gms. of mercury in 25 cc. of nitric acid diluted with 25 cc. of water at a lukewarm temperature. Mix this solution with one of 10 gms. of mercury in 20 cc. of fuming nitric acid.

(8) *Copper Sulphate or Ferric Sulphate.*—Dissolve 5 gms. of these salts respectively in 100 cc. of water.

(9) *Sodium Plumbite.*—Dissolve 5 gms. of caustic soda in 100 cc. of water and add 5 gms. of litharge (PbO), and boil until dissolved.

(10) *Ammoniacal Copper Oxide, Schweitzer's Reagent.**—Dissolve 5 gms. of copper sulphate in 100 cc. of boiling water, add caustic soda solution till the copper compound is completely precipitated, wash the precipitate of copper hydrate well, then dissolve in the least quantity of ammonia water. This gives a deep blue solution.

(11) *Ammoniacal Nickel Oxide.*—Dissolve 5 gms. of nickel sulphate in 100 cc. of water and add a solution of caustic soda until the nickel hydrate is completely precipitated; wash the precipitate well and dissolve in 25 cc. of concentrated ammonia and 25 cc. of water. This solution dissolves silk almost immediately, but reduces the weight of vegetable fibres only about $\frac{1}{2}$ per cent., and of wool only $\frac{1}{3}$ per cent.

(12) *Caustic Potash or Caustic Soda.*—Dissolve 10 gms. of the caustic alkali in 100 cc. of water.

(13) *Sodium Nitroprusside.*—Dissolve 2 gms. of the salt in 100 cc. of water.

(14) *Lead Acetate.*—Dissolve 5 gms. of lead acetate crystals (sugar of lead) in 100 cc. of water.

(15) *Sulphuric and Nitric Acids.*—The commercial concentrated acids are employed.

(16) *Chlorin Water.*—Water is saturated with chlorin gas obtained by acting on pyrolusite (MnO_2) with hydrochloric

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* Böttcher recommends that this solution be prepared as follows: A glass tube about 2 inches in diameter and 24 inches in length is loosely filled with thin sheet copper and then filled up with ammonia water. After a few minutes, the liquid is drawn off, and then poured over the copper again. This process is repeated during several hours, when a deep-blue saturated solution of ammoniacal copper oxide is obtained. Neubauer recommends to precipitate a solution of copper sulphate with caustic soda in the presence of ammonium chloride; the precipitate so obtained is washed several times by decantation and finally on a filters It is then dissolved in the least quantity of ammonia water. Wiesner prepare. the solution by digesting copper turnings with ammonia water in an open flask.

acid. The solution should be preserved in amber-colored bottles.

(17) *Iodin Solution.*—Dissolve 3 gms. of potassium iodide in 60 cc. of water, and add 1 gm. of iodin. Dilute this solution, before using, with 10 parts of water. When the reaction is employed in connection with sulphuric acid, the latter consists of 3 parts of concentrated sulphuric acid, 1 part of water, and 3 parts of glycerol. The glycerol has the effect of preventing injury to the fibres, and at the same time brings out certain details of the structure when the fibres have previously absorbed the iodin. The fibres are moistened first with the iodin solution and then with the sulphuric acid solution.

(18) *Picric Acid Solution.*—Dissolve 0.5 gm. of picric acid in 100 cc. of water.

A delicate reaction * for detecting the presence of vegetable fibres in wool is the following: The sample of material under examination is well boiled with water to remove any finishing materials that might be present and interfere with the reaction. Then a small portion of the sample is put in a test-tube with 1 cc. of water and 2 drops of an alcoholic solution of alpha-naphthol and about 1 cc. of concentrated sulphuric acid. If vegetable fibres are present, they will be dissolved and the liquid will acquire a deep violet color when shaken; the animal fibres only give a yellow to reddish brown coloration but no violet tint. If thymol is used instead of alpha-naphthol, a beautiful red coloration will be produced in the presence of vegetable fibres. Cross and Bevan have devised a delicate test which is serviceable for detecting the presence of vegetable fibres in fabrics: the sample of the cloth is immersed in a solution of ferric chloride and potassium ferrocyanide, when any vegetable fibre present will be colored blue.

Lieberman gives a test to distinguish between animal and vegetable fibres as follows: The fibres are boiled with a solution of magenta which has previously been decolorized by the addition of just sufficient caustic soda; then they are well washed and

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* Molisch, *Dingl. Polyt. Jour.*, 1886.

TABLE II.

Test.	Wool.	Silk.	Linen.	Cotton.	Hemp.	Jute.
Caustic potash..........	Dissolves	Dissolves	Swells up and becomes brown	Swells up and becomes yellowish	Colored	brown
Caustic soda...........	Dissolves gradually	Dissolves gradually and becomes reddish	Brown-yellow	Faintly yellow	Brownish	
Ammonia..............	—	—	—	—	Unretted, yellow; retted, violet	—
The alkali solution of the fibre treated with:						
Sodium nitroprusside...	Violet	Nil				
Lead acetate..........	Black	Nil	—	—	—	—
Copper sulphate.......	Violet then brown	Violet	—	—	—	—
Sulphuric acid.........	Does not dissolve till heated	Dissolves quickly in hot	Dissolves quickly in cold	Dissolves quickly	Dissolves slowly	Dissolves slowly
Nitric acid............	Yellow, dissolves slowly	Yellow, dissolves quickly	Dissolves without color	No color	Yellow color	—
Chlorin water..........	Yellow	Yellow	Bleaches	Bleaches	Yellow-brown	Violet on addition of ammonia
Iodin solution.........	—	—	Yellow	Yellow	—	Light brown
Picric acid............	Yellow	Yellow	Nil	Nil	Nil	Nil
Iodin and sulphuric acid...	—	—	Swells, blue	Swells, blue	Swells, green	Swells, yellow to brown
Thymol and sulphuric acid.	—	—	Violet	Violet	—	—
Sugar and sulphuric acid...	Rose-red	Rose-red	—	—	—	—

placed in water slightly acidulated with acetic acid. If the fibres are of animal origin, they will be colored a deep pink, whereas cotton and linen fibres will be unaffected.

Both this reaction and the one with picric acid (see Table II) are convenient to use when it is desirable to render visible the animal fibres in a mixed yarn or fabric. In case of a mixture of wool and silk fibres, the wool may readily be shown by placing the sample in a very dilute boiling solution of caustic soda containing a few drops of lead acetate solution. Any wool present will be turned brown by this treatment, due to the formation of lead sulphide from the sulphur which forms a constituent of this fibre. Silk (and also cotton or other vegetable fibre) will not be colored. In this test, of course, it will be necessary that the sample is undyed, or, at least, that all coloring-matters originally present be completely removed.

In strong, cold sulphuric acid silk quickly turns yellow and dissolves; cotton disintegrates slowly without color; flax and hemp make a black mixture, and wool is scarcely affected. Both silk and wool turn yellow and are soluble in nitric acid, the first more speedily, while vegetable fibres are slightly affected.*

The following analytical table showing the reactions of the more important vegetable fibres is given by Dodge: †

TABLE III.

Fibre.	Iodin and Zinc Chloride.	Iodin and Sulphuric Acid.	Cuprammonium.	Anilin Sulphate.	Phloroglucol.
Cotton.	Violet	Blue	Blue solution	—	—
Flax.	do.	do.	do.	—	—
Hemp.	do.	do.	do.	Pale yellow	Violet red
Jute.	Brown yellow	Green blue	do.	Golden yellow	Deep red
Ramie.	Dull violet	Dull blue	do.	—	—
Manila hemp.	Yellow to violet	—	—	Yellow	Red
New Zealand flax. ...	Golden yellow	Green blue	Bluish	Yellowish	Pale red
Aloe.	Yellow to brown	Yellow	Swells; bluish	do.	Pink
Cocoa.	do.	—	—	Bright yellow	Purplish

* Seaman, *On the Identifica ion of Fibres.*
† *Useful Fibre Plants, Bulle in No. 9* of U. S. Dept. of Agriculture

The solution of iodin and zinc chloride is prepared by taking 100 parts of zinc chloride solution of 1.8 sp. gr., adding 12 parts of water and 6 parts of potassium iodide, then add iodin until vapors of the latter begin to form. The brown liquid thus obtained should be preserved away from light. The cuprammonium solution is made by adding sodium carbonate to a solution of copper sulphate, whereby a mixed precipitate of copper hydrate and carbonate is obtained. This is well washed, and treated with just sufficient ammonia (of 0.91 sp. gr.) to dissolve it. The solution should be well shaken and filtered before using. The anilin sulphate is used as a 1 per cent. solution; this reagent colors cells of woody fibre pale to deep yellow in proportion to the amount of woody matter present. The phloroglucol reagent is applied as follows: first a drop or two of a 5 per cent. solution of phloroglucol in 95 per cent. alcohol is applied to the fibre under examination, and this is followed by the addition of a couple of drops of strong hydrochloric acid. Lignified cells will be stained red, while those not lignified will remain colorless. A similar solution of anilin hydrochloride may be substituted for the phloroglucol, in which case the lignified tissue will be stained yellow instead of red. The iodin and sulphuric acid is applied in a manner similar to that described on page 338.

In an examination of a sample the fibres should be separated into their ultimate cells by soaking in caustic alkali, then rubbing between the fingers, or teasing out with needles. If the separation of the cells is difficult by this means, recourse must be had to boiling the fibre in a 10 per cent. solution of caustic soda or Labarraque solution (sodium hypochlorite), and then fraying the fibre apart by rubbing in a mortar. After the fibre has been divided into its ultimate cells, they should be spread out on a slide moistened with glycerol; this will lessen the tendency of the cells to curl up. A cover-glass is then laid on, and the microscopical examination is made. In order to make an examination of the section of the fibre to determine the diameter of the cells, the following method is recommended: An imbedding mass is made by dissolving 70 gms. of clean gum arabic in an equal weight of distilled water; then 4 gms. of isinglass (gelatin) are

digested in 16 cc. of cold water till swollen, and heated to complete solution. One-half of this latter solution is strained through a piece of fine muslin (the rest is discarded) and mixed with the solution of gum arabic; 10 to 12 cc. of glycerol are added, the whole is well mixed and warmed. It is best preserved in small bottles containing a fragment of camphor. On cooling the mixture solidifies, but when it is to be used the bottle is warmed, a small bundle of fibres for examination are tied together and saturated with the glue, drawing the fibres out carefully till they are straight and parallel. The bundle is then hung up and dried for 12 hours, after which it will be firm enough to cut with a microtome. The slices thus obtained are placed on a slide, and moistened with the iodin solution; this dissolves the glue, which is absorbed by strips of blotting-paper and thus removed. With soft fibres that are easily cut, a section may be more simply obtained by soaking in melted paraffin, and, after cooling, cutting on the microtome. The wax may be removed from the section by dissolving in benzene or turpentine.

Table IV shows the reaction of the various vegetable fibres with the iodin-sulphuric acid reagent, together with the length and diameter of the ultimate fibre-cells in millimetres.

Allen * summarizes in Table V the reactions to distinguish silk qualitatively from other fibres.

3. Distinction between Cotton and Linen.—As it is often desirable to discriminate between these two fibres, the following tests, as suggested by various authorities, are given:

(1) The fibre is burnt:

Cotton—burnt end tufted.

Linen—burnt end rounded.

(2) The fibre is immersed in concentrated sulphuric acid for two minutes, washed well with water, then with dilute ammonia water, and dried:

Cotton—forms a gelatinous mass soluble in water.

Linen—the fibre is unaltered.

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* *Commer. Org. Anal.*, vol. 4, p. 518.

TABLE IV.

Common Name.	Botanical Name and Reaction with Iodin-sulphuric Acid Reagent.	Length of Cells, mm.			Diameter of Cells, mm.			Remarks.
		Min.	Aver.	Max.	Min.	Aver.	Max.	
	Dicotyledons giving blue reaction:							
Flax	Linum usitatissimum	4.	30.	66.	0.055	0.022	0.037	Cavity fine; yellow line.
Hemp	Cannabis sativa	5.	25.	55.	0.016	0.022	0.050	Striated; yellow sheath.
Hop	Humulus lupulus	4.	10.	19.	0.012	0.016	0.018	
Nettle	Urtica sp.	4.	27.	55.	0.020	0.050	0.070	
China grass	Boehmeria nivea	60.	120.	200.	0.050	0.080	—	
Paper mulberry	Broussonetia papyrifera	6.	15.	25.	0.025	0.030	0.035	Canal scarcely apparent.
Sunn	Crotalaria juncea	4.	7.8	12.	—	—	—	Yellow envelop.
Broom	Cytisus scoparius	2.	6.	9.	—	—	—	
Spanish broom	Spartium junceum	5.	10.	16.	—	—	—	Cavity large.
Melilot	Melilotus alba	5.	10.	18.	—	—	—	Flattened and twisted.
Cotton	Gossypium sp.	10.	25.	40.	—	—	—	
	Dicotyledons giving yellow reaction:							
Hibiscus	Hibiscus sp.	2.	5.	6.	0.014	0.021	0.033	Color more intense on surface.
Linden	Tilia sp.	1.25	2.	5.	0.014	0.016	0.020	Canal very small.
Jute	Corchorus sp.	1.5	2.	5.	0.020	0.020	0.025	Stiff; canal prominent.
Lace bark	Lagetta lintearia	3.	5.	6.	0.010	0.015	0.020	
Willow	Salix alba	—	3.	3.	0.017	0.022	0.030	
	Monocotyledons giving blue reaction:							
Esparto	Lygeum spartum	1.3	2.5	4.5	0.012	0.016	0.020	Curly; cavity small.
Spanish grass	Stipa tenacissima	0.5	1.5	3.5	0.007	0.013	0.018	Cavity fine; coloration slight.
Pineapple	Ananas sativa	3.	5.	9.	0.004	0.006	0.008	
	Monocotyledons giving yellow reaction:							
New Zealand flax	Phormium tenax	5.	9.	15.	0.010	0.015	0.020	Coloration intense.
Adam's needle	Yucca sp.	5.	4.	6.	0.010	0.015	0.020	
Bowstring hemp	Sansevieria sp.	1.5	3.	6.	0.015	0.020	0.026	
Century plant	Agava americana	1.5	2.5	4.	0.020	0.024	0.032	
Manila hemp	Musa textilis	3.	6.	12.	0.016	0.024	0.032	

TABLE V.

Test.	Silk, Wool, Fur, or Hair.		Cotton or Linen.
Heated in a small test-tube	Brittle, carbonaceous residue, and odor of burnt feathers. Gases and condensed moisture alkaline to litmus		Charring and smell of burning wood. Gases and condensed moisture acid to litmus
Boiled on a saturated aqueous solution of picric acid and rinsed in water	Dyed yellow		Unchanged
Boiled with Millon's reagent	Red coloration		No change of color
Treated with cold nitric acid (1.2 sp. gr.)	Colored yellow		No change of color
Moistened with dilute hydrochloric acid and dried at 100° C.	Unchanged		Becomes rotten
	Silk.	Wool, Fur, or Hair.	
Heated to boiling with hydrochloric acid	Dissolved	Swells, without at once dissolving	Mostly undissolved
Boiled with a conc. solution of basic zinc chloride	Dissolved	Unchanged	Unchanged
Treated with cold Schweitzer's reagent	Dissolved; not precipitated by addition of salts	Undissolved; dissolves on heating	Dissolved; solution precipitated by addition of salts
Treated in the cold with 10 per cent. caustic soda	Undissolved	Dissolved	Undissolved
Boiled with a 2 per cent. solution of caustic soda	Dissolved; solution not darkened by lead acetate; negative reaction with sodium nitroprusside	Dissolved; solution gives black or brown precipitate with lead acetate and violet color with sodium nitroprusside	Unchanged
Behavior with Molisch's test	Dissolved, with little coloration	Undissolved, with yellow or brown coloration	Dissolved, with deep violet color

(3) The fibre is treated with an alcoholic solution of madder for fifteen minutes:

Cotton—becomes bright yellow in color.

Linen—becomes dull orange-yellow in color.

(4) The fibre is treated with an alcoholic solution of cochineal for fifteen minutes:

Cotton—becomes bright red in color.

Linen—becomes violet-red in color.

(5) The fibre is immersed in olive oil or glycerol, after previously being boiled in water and well dried:

Cotton—remains opaque and white.

Linen—becomes translucent by reason of the oil rising by capillary action between the individual filaments of the fibres.

(6) The fibre is treated with an alcoholic solution of rosolic acid, and then with a concentrated caustic soda solution:

Cotton—remains colorless.

Linen—becomes rose-red in color.

(7) The fibre is treated with iodin and sulphuric acid solutions:

Cotton—becomes pure blue in color.

Linen—gives a dull blue color. This test is satisfactory only on unbleached linen.

(8) A small portion of the sample is boiled in a solution of equal parts of water and caustic potash; at the end of two minutes the sample is raised with a glass rod and placed between several thicknesses of filter-paper to remove the excess of water:

Cotton—remains white or is a pale, clear yellow in color.

Linen—becomes dark yellow in color. This test is adapted only for white goods.

(9) Kuhlmann recommends the use of a cold concentrated solution of caustic potash (1.6). This causes unbleached *cotton* to shrink and curl up, and to become gray or dirty white in color; whereas unbleached *linen* shrinks more than cotton, and acquires a yellowish orange color.

(10) The fibres are boiled in water, dried, immersed in a saturated solution of sugar and common salt, and dried. The separate threads are then ignited:

Cotton—leaves a black-colored ash.

Linen—leaves a gray-colored ash.

(11) The fibres are treated with a 1 per cent. alcoholic solution of magenta (fuchsin), and then washed with a weak solution of ammonia:

Cotton—at first stained a rose color which is washed out by the ammonia.

Linen—the rose color is permanent.

(12) Herzog* recommends the following test to distinguish between cotton and flax in a woven fabric: A small piece of the cloth is cut out and the edges are fringed. The sample is then steeped for a few minutes in a lukewarm alcoholic solution of cyanin; it is then washed with water and treated with dilute sulphuric acid. By this treatment the cotton is completely decolorized, while flax retains a distinct blue coloration. To make the blue color still more distinct, the material should be washed free from acid and placed in ammonia. The coloration is said to be due to the presence on the flax fibre of fragments of epidermis which readily absorbs the dyestuff.

These tests will only satisfactorily distinguish linen from cotton when the former is unbleached. Bleached linen shows scarcely any difference from cotton in the tests.

4. Distinction between New Zealand Flax (*Phormium tenax*), **Jute, Hemp, and Linen.**—The following series of tests is recommended to distinguish between the fibres in question:

(1) The material is immersed in chlorin water for one minute, then spread on a porcelain dish, and several drops of ammonia water added. New Zealand flax and jute become at first bright red in color, which afterwards changes to dark brown; linen and hemp acquire a much lighter shade, such as clear brown, orange, or fawn. This method is very good for yarn or unbleached cloth, and is particularly well adapted for testing sailcloth. French hemp retted in stagnant water is colored a much deeper shade than the same kind of hemp retted in running water; in either case the color is much darker than that acquired by linen. For testing twine this method is said to give excellent

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* *Zeit. f. Farben- und Text. Ind.*, 1905, p. 11.

results, but in bleached material the difference in the shades pro-
duced is not very marked.

(2) To test bleached material, the sample is immersed for
one hour, at 36° C., in nitric acid containing nitrous oxide. New
Zealand flax assumes a blood-red color, while linen or hemp is
tinted pale yellow or rose, according to the method by which it
was originally retted.

(3) A sample of the material is heated in concentrated hydro-
chloric acid. Hemp and linen will not become colored, whereas
New Zealand flax becomes yellow at a temperature of 30° to
40° C., then becomes red, brown, and finally black.

(4) A sample of the material is treated with a solution of
iodic acid. Hemp and linen are not affected, but New Zealand
flax acquires a rose-red color.

(5) Jute is distinguished from New Zealand flax by soaking
the fibres for two to three minutes in a solution of iodin, and
then rinsing several times in a 1 per cent. solution of sulphuric
acid to remove excess of iodin. Jute acquires a characteristic
reddish brown color; New Zealand flax becomes clear yellow
in color; hemp acquires a light yellow color, and linen a blue
color. It will be found best to untwist the separate threads pre-
vious to this treatment. For the preparation of the iodin and
sulphuric acid solutions, see page 338.

(6) Jute may be distinguished from flax and hemp by warming
in a solution containing nitric acid and a little potassium chromate,
then washing and warming in a dilute solution of soda ash, and
washing again. The fibres are then placed on a microscope slide,
and when the water has evaporated a drop of glycerol is added,
In a short time the characteristic structure of jute will be easily
observable, and under the polariscope (with a dark field) the jute
fibre will show a uniform blue or yellow color, whereas linen and
hemp will show a play of prismatic colors. Also with phloroglucol
and hydrochloric acid, jute is stained an intense red, while linen
remains uncolored and hemp acquires only a reddish tint.

(7) To distinguish accurately between linen and hemp *

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* *Distinction between Manila hemp and sisal.*—In their characteristics these two
fibres are very similar and it is quite difficult to distinguish between them. This

it is best to have recourse to a microscopic examination. The linen fibres will appear quite regular and with a lumen which is often reduced to a mere line, while the hemp fibre shows a very large lumen, and presents a rather irregular surface. With the iodin-sulphuric reagent hemp gives a green coloration, while linen gives a blue; with nitric acid linen gives no color, while hemp shows a pale yellow coloration. The ends of the linen fibres are pointed, while those of hemp are enlarged and spatula-shaped.

5. Ligneous Matter (derived from woody tissue) may be detected in admixture with other fibres in the following manner:

(1) On exposing the moistened sample to the action of chlorin or bromin, and then treating it with a neutral solution of sodium sulphite, a purple color will be produced.

(2) If the sample be moistened with an aqueous solution of anilin sulphate, an intense yellow color will be produced.

(3) If the sample be moistened with a solution of phloro-glucol of $\frac{1}{2}$ per cent. strength, and then with hydrochloric acid, an intense violet-red color will be produced. Solutions of resor-cinol, orcinol, and pyrocatechol act in a similar manner.

(4) Woody fibre when boiled in a solution of stannic chloride containing a few drops of pyrogallol gives a fine purple color, which is easily seen under a magnifying-glass.

6. Reactions of Bast Fibres.—In Table VI, by Goodale, are presented reactions for the principal bast fibres.

7. Systematic Analysis of Mixed Fibres.—Table VII, by Pinchon, represents an attempt to give a systematic qualitative analysis of the most important textile fibres.* With a due degree of caution, this schematic analysis may be employed with con-

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may be done, however, with more or less accuracy by an observation of the color of the ash, which in the case of Manila hemp is grayish black, while sisal leaves a white ash.

* The fibre is first treated with a 10 per cent. solution of caustic potash, which causes any animal fibre to dissolve, the vegetable fibres remaining insoluble. If lead acetate solution is added to the fibre after treatment with caustic potash, if wool is present it will become dark, owing to the formation of lead sulphide from the sulphur existing in the wool. If silk is suspected, warm in concentrated sulphuric acid, which will cause the silk to darken rapidly and the wool more slowly.

TABLE VI.—REACTIONS OF BAST FIBRES.

Name of Fibre.	Reaction with Schweitzer's Reagent.	Reaction with Iodin and Sulphuric Acid.	Reaction with Anilin Sulphate.	Length of Raw Fibre, cm.	Width, mm.	Length of Bast-cells, mm.	Width of Bast-cells.	
							Limit mm.	Av'age mm.
Raw flax	Soon attacked and enmost entirely dissolved	Colored blue	Remains uncolored	20-140	.04-.62	20-40	.012-.076	.015
Raw hemp	Clean fibre dissolved	Greenish blue to pure blue	Faint yellow	100-300	—	10	.015-.028	.016
Raw jute	Bluish color; more or less distinct swelling	Yellow to brown	Golden yellow to orange	150-300	.03-.14	.8-4.1	.010-.021	.016
Raw esparto	Bright green	Rusty red	Egg-yellow	10-40	.09-.50	.5-1.9	.009-.015	—
Raw aloe	Bluish color; feeble swelling	Reddish brown	Golden yellow	40-50	.075-.105	1.3-3.7	.015-.024	—
New Zealand flax	Bluish color; more or less swelling	Varies, with purity of fibre, yellow, green, or blue	Uncolored	80-110	.042-.12	2.5-5.6	.008-.019	.013
China grass	When "cottonized" quickly acted upon, and almost completely dissolved	Copper-red to blue	Uncolored	—	—	220	.040-.080	.050
Ramie	do.	do.	do.	—	—	80	.016-.126	—
Coir	Perceptible swelling; blue color	Reagent not applicable on account of color of fibre	Not applicable	15-33	.05-.30	.4-.96	.012-.020	.016
Agave	Swells and becomes somewhat blue	With iodin sol., yellow; on addition of H_2SO_4, brown	Yellow	100	.10-.46	1.02-2.22	.016-.021	.017
Manila	Blue color and feeble swelling	With iodin sol., yellow; on addition of H_2SO_4, greenish	Pale yellow	750	.010-.28	2.0-2.7	.012-.046	.029

TABLE VII.—TABLE FOR ANALYSIS OF MIXED FIBRES (PINCHON).

The mixture is boiled with 10% KOH for 20 minutes

Completely dissolves			Partially dissolves		
			Another sample is boiled 5 minutes with zinc chloride solution		
The whole dissolves		The alkaline solution does not blacken on the addition of lead acetate: *Silk*	Remains undissolved		
Part dissolves		The dissolved portion is not blackened by lead acetate, but the insoluble portion does: *Silk and Wool*	Chlorin water (or ammonia) colors the fibre	Red-brown	The fibre is colored red by fuming nitric acid: *New Zealand Flax*
None dissolves		The mass is blackened by lead acetate: *Wool*			Alcoholic fuchsin colors the fibre
			Not at all	Permanently	Caustic potash stains yellow — Iodin and sulphuric acid color: Yellow *Hemp* / Blue *Flax*
				Color removed by washing	No yellow color with caustic potash: *Cotton*
			Part dissolves — On addition of lead acetate is	Blackened	Caustic potash partly dissolves the fibres insoluble in zinc chloride; the remaining fibres are soluble in ammoniacal copper oxide: *Wool, Silk, and Cotton*
				Not blackened	Picric acid colors portion yellow, the residue remaining white: *Silk, Cotton*
			None dissolves		Nitric acid colors portion yellow, the residue remaining white: *Flax, Cotton*

siderable success, though confirmatory tests should be applied to the detection of each fibre indicated. The differentiation between the various vegetable fibres given is especially difficult.

8. Identification of Artificial Silks.—In Table VIII are given Hassac's tests to identify the different varieties of artificial silks or forms of lustra-cellulose, and also the distinction between these latter and true silk.

9. Distinction between True Silk and Different Varieties of Wild Silk.—True silk (from *Bombyx mori*) rapidly dissolves (one-half minute) in boiling concentrated hydrochloric acid; Senegal silk (from *Faidherbia*) dissolves in a somewhat longer time, while yama-mai, tussah, and cynthia silks require a much longer time for complete solution. True silk is also rather easily soluble in strong caustic potash solution, whereas the other varieties of silk are not. The most approved reagent, however, for separating true silk from the wild varieties is a semi-saturated solution of chromic acid, prepared by dissolving chromic acid in cold water to the point of saturation and then adding an equal volume of water. True silk is completely dissolved on boiling in this solution for one minute, whereas wild silk remains insoluble.

Under the microscope true silk can readily be told from wild silks, as the latter fibres are broad and flat, and show very distinct longitudinal striations, which are absent in true silk. Exception must perhaps be made with the wild silk from *Saturnia spini*, which can scarcely be told from true silk by a microscopical examination. With regard to distinguishing between the different varieties of wild silks themselves, some valuable information may be gained by a determination of their relative diameters. Höhnel gives the following values for the greatest thickness of the different silks:

True silk	(*Bombyx mori*)	20 to 25 μ
Senegal silk	(*Faidherbia bauhini*)	30 to 35 μ
Ailanthus silk	(*Attacus cynthia*)	40 to 50 μ
Yama-mai silk	(*Antheræa yama-mai*)	40 to 50 μ
Tussah silk	(*Bombyx selene*)	50 to 55 μ
Tussah silk	(*Bombyx mylitta*)	60 to 65 μ

According to Wiesner and Prasch, the breadths of the single fibres of different silks are as follows:

TABLE VIII.—IDENTIFICATION OF ARTIFICIAL SILKS.

Reagent	Natural Silk.	Collodion Silk.	Cellulose Silk.	Gelatin Silk.
Water	No change	Swell up; addition of alcohol or glycerin causes contraction again		
Conc. sulphuric acid	---	Swells rapidly and dis- solves	Gradually be- comes thin- ner and dis- solves	Only dissolves on heating
Acetic acid	—	Slight swell- ing	Slight swell- ing	Dissolves on boiling
Half-saturated sol. of chromic acid	Dissolves slow- ly	Dissolves in the cold		
Diphenylamin and sulphuric acid	—	Blue color	—	—
Caustic potash, 40%	Dissolves with- out color	Swell without dissolving, but color liquid yellow		Dissolves rap- idly
Ammoniacal cop- per solution	—	Swells quickly and dis- solves	Swells slowly and dis- solves	Insoluble; col- ors liquid violet
Alkaline copper glycerin solu- tion	Dissolves im- mediately at 80° C. tus- sah silk dis- solves in one minute on boiling	Unchanged	Unchanged	Dissolves on boiling
Iodin in potas- sium iodide	—	An intense red color which disappears on washing		
Iodin and sul- phuric acid	Yellow	Deep violet- blue	Pure blue	Yellowish to reddish brown
Iodin in zinc chloride	Becomes yel- low and dis- integrates	Blue-violet	Gray-blue to gray-violet	Becomes yellow and disinte- grates
Ignition	Odor of burnt feathers	No odor	No odor	Odor of burnt feathers

Ailanthus silk.	7 to 27, mostly 14 μ
Yama-mai silk	10 to 45, mostly 23 μ
Bombyx mylitta.	14 to 75, mostly 42 μ
Bombyx selene.	27 to 41, mostly 34 μ
Senegal silk	12 to 34, mostly 22 μ
True silk.	9 to 21, mostly 13 μ

True silk, ailanthus silk, and Senegal silk do not show any cross-marks, or only very faint indications of such; whereas with tussah silk and yama-mai silk the cross-marks are very distinct and characteristic.

The microscopical appearance of the end of the fibre on being torn apart also serves at times as a useful means of distinguishing the variety of silk; true silk, tussah silk, and yama-mai silk show scarcely any fraying at the ends; in Senegal silk the fraying is very noticeable in almost every fibre; while in ailanthus silk about one-half of the number of fibres show a frayed end.*

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* Besides the wild silks mentioned above, there are a few others of lesser importance, which for the sake of completeness are herewith described:

1. *Saturnia polyphemus*, a North American variety, consists of very flat fibres, with large air-canals and numerous structural filaments separating at the edge of the fibre; coarse lumps of adhering sericin are frequent; well-defined cross-marks are also frequent. The single fibre is about 33 μ in width; in its polariscopic appearance these fibres very much resemble ailanthus silk.

2. *Arryndia ricini:* the fibres are even more flattened than the preceding and resemble a thin band or ribbon; large air-canals are of frequent occurrence; striations very apparent; the sericin layer is in places very thin, and sometimes apparently lacking altogether. The double fibre is about 45 to 55 μ in width, and 4 to 6 μ thick. At the edge of the fibre frayed ends of structural filaments are often apparent. Cross-marks are rather ill-defined, but of frequent occurr, rence. The sericin layer, though thin, is quite uniformly developed.

3. *Antherœa pernyi* has a very flat fibre, resembling a ribbon; it does not fray out at the ends, and shows scarcely any single filaments. The double fibre measures 60 to 80 μ in width and 8 to 10 μ in thickness. Cross-marks are rather few and indistinct. The sericin layer is very thin, and in general hardly noticeable. Moderately sized air-canals are present.

4. *Saturnia cecropia* occurs in Texas. The fibre is also flat and ribbon-like in form; the double fibre measures 60 to 90 μ in width and 10 to 15 μ in thickness; air-canals are frequent and large, hence the fibre usually appears rather dark under the microscope. The cross-marks are very distinct, and at such points the fibre is much broader. The fibre is usually much frayed out and individual filaments are easily distinguished. The sericin layer is quite thin, but very uniform.

5. *Attacus lunula* has fibres which are not so flat as the preceding. The double fibre is 25 to 35 μ in width and 12 to 18 μ in thickness. The air-canals

By the use of the polariscopic attachment to the microscope, considerable differences can be observed in the interference colors displayed by the different varieties of silks. It is best to conduct these observations under a magnification of 30 to 50 diameters; and as the silk fibres are more or less ovoid in section, it must be borne in mind that the same fibre will give a different color phenomenon, depending on whether it is viewed from the narrow side or from the broad side. Hence, to obtain trustworthy results, the appearance of the same side only of the fibres should be compared. Also, the appearance of single fibres only, and not of crossed fibres, should be taken. Höhnel gives the following description of the appearance of the different silk fibres viewed in polarized light, the observations being made with a dark field, and under a magnification of 30 to 50 diameters:

1. *True silk:* (*a*) *broad side*, very lustrous, of a bluish or yellowish opalescent white; the same color is nearly always to be found over the entire breadth; (*b*) *narrow side*, exactly similar to the preceding.

2. *Yama-mai silk:* (*a*) *broad side*, generally of a pure bluish opalescent white; also darker bluish to almost black tones; nearly all of the colors are brilliant; (*b*) *narrow side*, shows all colors, very brilliant and contrasted; darker and blackish tones also occur.

3. *Tussah silk* (from *Bombyx selene*): ·(*a*) *broad side*, shows all colors, very brilliant; thickness of the fibre very uneven, hence the colors change through the length; the thick parts are dark blue and reddish violet, while the thinner parts are yellow or orange; (*b*) *narrow side*, shows bright red and bright green colors, though often but slightly visible; the colors form long flecks; often only dark gray to black.

4. *Tussah silk* (from *Bombyx mylitta*): (*a*) *broad side*, a bluish opalescent white prevailing; also brown, gray, and black tones; the colors occur in flecks like preceding, though scarcely

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are fine and delicate; and the fibre shows but a slight degree of fraying. The sericin layer is very thin and finely granulated on the surface; in places it has the form of irregular shreds. The fibre as a whole has a brownish yellow appearance, due to the ochre-yellow color of the sericin layer.

even dark blue, but mostly bright orange to red or brown; (*b*) *narrow side*, color a dull gray with bright red or green flecks; the general appearance is very similar to the preceding silk.

5. *Ailanthus silk:* (*a*) *broad side*, bright yellow or yellow-brown to gray-brown colors; (*b*) *narrow side*, nearly all colors, but rather soft and not very contrasted, seldom very bright, but rather dull; short flecks of green, yellow, violet, red, or blue.

6. *Senegal silk:* (*a*) *broad side*, bright yellowish white, gray to brown, seldom bluish white in color; (*b*) *narrow side*, faint and dull gray, brown to blackish colors, seldom bright colors.

10. Micro-analytical Tables.—The following micro-analytical tables have been adopted from Höhnel for the qualitative determination of vegetable fibres:

I. TABLE FOR THOSE VEGETABLE FIBRES BOTANICALLY
DESIGNATED AS HAIR STRUCTURES.

1. (*a*) Each single fibre consists of a single cell........(see 4).

(*b*) Each fibre consists of two cells, namely, a short, thick, underlying cell, and an overlying pointed, principal cell. The fibres are grayish brown, scarcely 0.5 cm. long; hard, woolly, lifeless, thin-walled, but round-stapled. Such fibres form the thick upper coating on the leaves of the *Cycadæ macrozamia* of New South Wales, and are used as vegetable hair in upholstery.

(*c*) Each single fibre consists of a series of cells, hence is a cellular fibre. The cells are golden yellow to brown in color, generally clinging together, and empty. The fibre as a whole is highly lustrous, but very harsh and brittle; very thin-walled, flat, and ribbon-shaped; frequently twisted on its axis; broad and 0.5 to 2 cms. long. Such fibres form the thick coating on the leaves of various ferns (*Cibotium*) in Asia, Australia, and Chili. The material is used for upholstery under the name of *pulu*.

(*d*) Each fibre consists of numerous cells growing side by side, or of several series of such; forms the so-called tuft......(see 2).

2. (*a*) Hairs straight, stiff; white to dirty yellow in color..(see 3).

(*b*) Hairs woolly, tough, brownish violet in color, 4 to 6 mm. long; consisting of long cotton-like, flat, twisted, spiral cells,

the walls of which are frequently thick and undulating; the contents of the cells moderately abundant, yellow to violet, and in part colored red with hydrochloric acid. This fibre covers the small, egg-shaped, flattened fruit of the new Holland plant

FIG. 112.—The Lesser Cotton Grass (*Eriophorum latifolium*). (After Dodge.)

Cryptostemma calendulaceum. It is used in Australia as a stuffing material.

(*c*) Hairs woolly, harsh, reddish yellow in color; the cells are very thin-walled, colorless, and generally empty; in places, however, filled with a homogeneous reddish yellow substance; where two cells come together side by side there are to be noticed round spots. The individual cells are relatively broad, extremely varied.

and irregularly thick; irregularly bent in places and frequently knitted together. This fibre forms the coating of a plant (*Hibiscus?*) growing in Cuba; as employed for upholstery materials it goes by the name of *Majagua*.

Fig. 113.—Cotton Grass (*Eriophorum angustifolium*). (After Dodge.)

3. (*a*) The hairs are 1 to 3 cm. long, and on the average are under 50 μ wide; they consist of two layers of cells which grow into one another. The inner walls are rough; the outer walls are thin and indented, hence lie close against the inner portion; the section walls are quite noticeable and thick; the tufts end in 2 to 6 pointed, often hook-shaped cells; the end cells show numerous pores; weakly lignified. This fibre consists of the ripe fruit

spicula of cotton-grass, *Eriophorum angustifolium, E. latifolium,*
etc...............................*Cotton-grass* (see Fig. 114).

(*b*) The fibres are 5 mm. long; mean breadth of the tufts
8 to 16 μ, the widest being under 30 μ; the tufts do not end with
sharp-pointed cells; the section-walls under low magnification
appear as little knots and are usually quite noticeable. This
fibre is obtained from the small, lance-like fruit of the reed
mace, *Typha angustifolia,* which grows on a small shaft, and

FIG. 114.—Fibres of Cotton Grass or Vegetable Silk. ($\times$50.) The sharp fractures
show the brittle nature of the fibre. (Micrograph by author.)

carries the hairs on the other end. It is used for upholstery and
other filling material..............*Reed-mace hair* (see Fig. 115).
4. (*a*) The fibres are flat, woolly, frequently twisted in a spiral
manner on their axes; not lignified...................(see 5).

(*b*) The fibre is generally cylindrical, stiff, not twisted; some-
what lignified, hence colored red with indophenol or phloro-
glucol..(see 6).
5. (*a*) Fibres 1 to 5 cm. long; white to yellowish brown; 12
to 42 μ thick...........................*Cotton* (see Fig. 116).

(*b*) Fibres only 9.5 cm. long; very thin; usually consisting of
tufts; violet-brown in color. See above, under 2 (*b*).

Cryptostemma hairs.
6. (*a*) The product consists of grassy spicula with a hairy cover-
ing; the hairs are 5 to 8 mm. long and about 10 to 15 μ wide;
the thickness of the wall of the thick, cylindrical-pointed hairs

remains rather uniform up to the point itself, hence the latter appears very thick; spots are often observed. This fibre is upholstery material from *Saccharum officinale*............*Sugar-cane hairs.*

(*b*) The product consists of short white fibres, about 8 to 24 μ in width, and of oval, flat fruit-shells, 4 mm. wide and 5 mm. long; the hairs are broadened at the base, hence generally knife-shaped; thick-walled, with transverse, fissure-like marks; the upper portion of the hair is very thin and rough-walled; colorless; the ends are usually blunt and contain a granular matter; slightly lignified, especially at the base.

Poplar cotton.

(*c*) The product consists entirely of hairs and is almost entirely free from accidental impurities........*Vegetable down and silk.*

7. (*a*) The fibres have two to five longitudinal ridges on the walls, which are either crescent-shaped or quite flat, running into network at the base; these ridges are broad and difficult to discern in a surface view of the fibre, yet sometimes very apparent; the maximum thickness about 35 μ; white or yellowish in color. These fibres are the seed-hairs of *Apocyneen* and *Asclepiadeen*.

Vegetable silk (see Fig. 119).

(*b*) The fibres are without ridges; transverse ridges frequently at the base or as a network. Maximum thickness generally under 35 μ; yellowish to brown. These fibres consist of the hairs which cover the fruit-pods of *Bombaceæ*.

Vegetable down (see 13).

8. (*a*) The hairs are 3.5 to 4.5 cm. long, and the largest are 50 to 60 μ in diameter...(see 9).

(*b*) The fibres are 1.5 to 4 cm. long, and the largest are 35 to 45 μ in diameter...(see **10**).
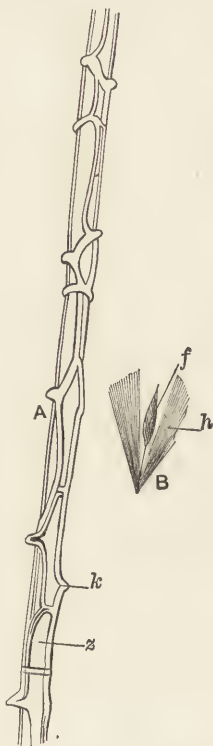
Fig. 115. — Reed - mace Hair. ($\times$340.) (Höhnel.) *A*, portion of hair; *B*, ripe fruit at *f*; *h*, hair around fruit; *z*, cells; *k*, knotted structure.

9. (*a*) The fibres are narrowed at the base, and directly above are strongly swollen, and up to 100 μ in thickness; numerous pores at the base; the fibres grow brush-like on a stem, are yellowish and harsh. This is vegetable silk from Senegal.

Strophantus (see Fig. 117).
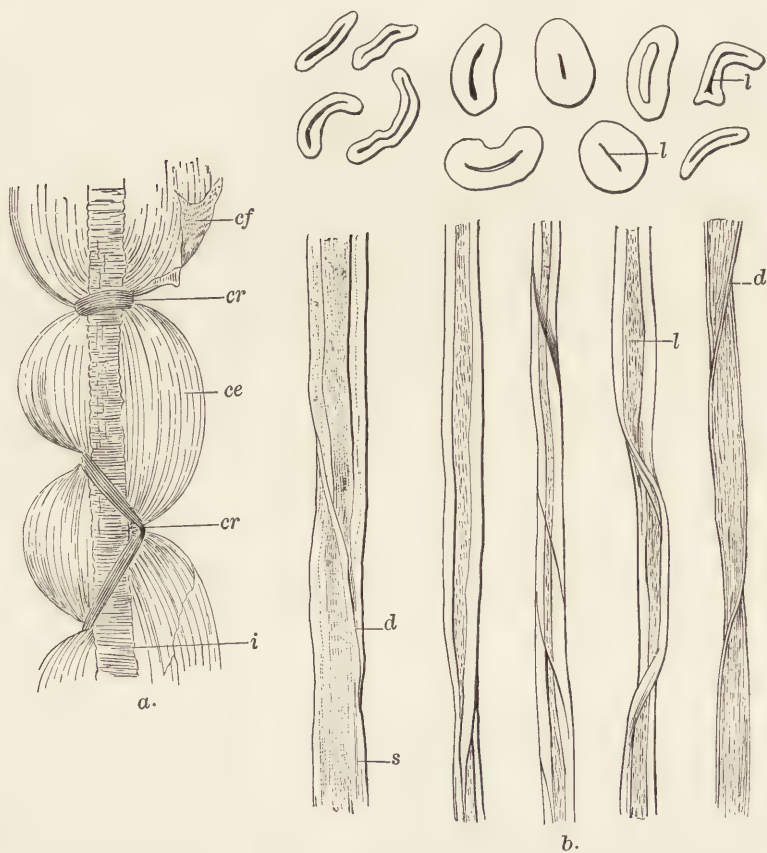
FIG. 116.—Cotton Fibres. ($\times$340.) (Höhnel.) *a*, portion swollen with Schweitzer's reagent; *cf*, shreds of cuticle; *cr*, rings of cuticle; *ce*, cellulose; *i*, dried protoplasmic canal; *b*, various cotton fibres with sections above; *l*, lumen; *d*, twists; *s*, granulations on cuticle.

(*b*) The fibres are white, firm, and tough, not harsh; form a hairy tuft or crown. This is vegetable silk from India.

Beaumontia grandiflora (see Fig. 118).

(*c*) Yellow rod fibres, weak, stiff, straight, and harsh.

Calotropis procera, Senegal.

10. (*a*) At base of the hair there are spots or pores...(see 11).

(*b*) Spots or pores lacking. Vegetable silk from *Asclepias cornutii, curassavica*,* etc.........................(see Fig. 119).

11. (*a*) Spots large; round or oblique; the walls of the fibre are not thicker at the base than at the upper portion; the ridges on
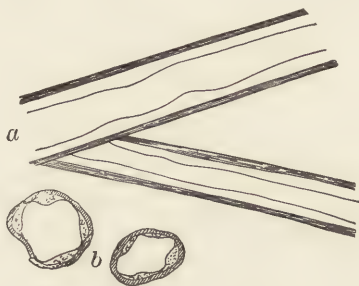
FIG. 117.—Fibre of *Strophantus*. (×300.) *a*, longitudinal view; *b*, cross-section. (Micrograph by author.)

the fibre are remarkably well developed, the hairs are strongly bent back at the base. Vegetable silk from *Calotropis gigantea*.

(*b*) Spots small, no longitudinal markings; walls thicker than the foregoing fibre; ridges less noticeable and often apparently lacking...(see 12).

12. (*a*) Hairs narrowed at the base............*Hoya viridiflora*.

(*b*) Hairs not narrowed at all, or scarcely so.....*Marsdenia*

13. (*a*) The hairs have mesh-like ridges at the base situated obliquely, or have spiral ridges........................(see 14).

(*b*) Without mesh-like ridges at the base..........(see 15).

14. (*a*) Base broader, thin-walled, with oblique, mesh-like ridges or spiral swellings, which often extend to a considerable distance. Points very thin-walled, gradually tapering, not ended sharply; frequently containing a reddish-brown homogeneous granular substance; fibre not very stiff, usually notched. Base

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* This plant grows in tropical and sub-tropical America and is also found in India. Its seed-hairs are said to be stronger than those of most other varieties of such fibres.

contains no marrow.   *Vegetable down from Eriodendron anfractuosum.*

(*b*) Quite similar, but the ends are not so tapering; without
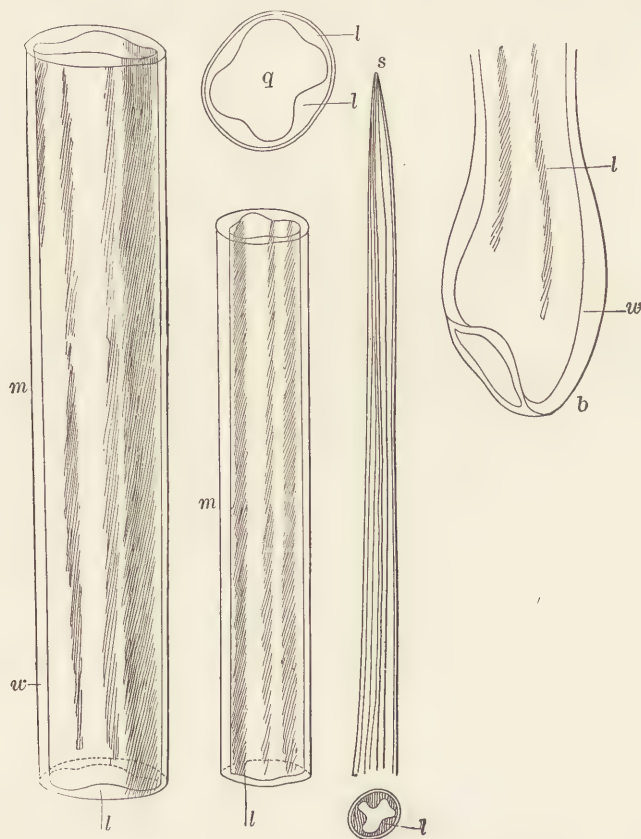
FIG. 118.—Vegetable Silk from *Beaumontia grandiflora.*   (×340.)   (Höhnel.)
b, base of fibre; *s*, pointed ends; *q*, cross section; *m*, middle portion of
fibre; *w*, cell-wall; *l*, longitudinal ridges.

marrow;   whole fibre somewhat rough-walled.   *Vegetable down from Bombax heptaphyllum.*

(*c*) Very similar to (*a*), but walls of fibre are quite roughened
and contain at intervals throughout its length a granular marrow;
base thick-walled, mesh-like fibrous ridges, but neither spirally
developed nor very broad—at most only one-sixth of the width

of the fibre; ends, as before, thick-walled. *Vegetable down,
Ceiba cotton, from Bombax ceiba*....................(see Fig. 120).
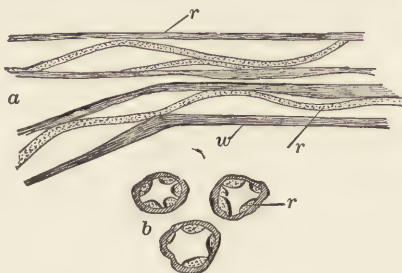
FIG. 119.—Vegetable Silk from *Asclepias cornutii.* (×300.) *a*, longitudinal view;
b, cross-sections; *r*, thickened ridges; *w*, cell-wall. (Micrograph by author.)

15. (*a*) Raw fibre, brown, rough-walled; walls 1 to 7 μ thick;
not indented; points without marrow; stiff and very sharp at

FIG. 120.—Vegetable Down (*Bambax ceiba*). (×300.) (Micrograph by author.)

end; base not broadened, often contains granular matter *Vege-
table down from Ochroma lagopus*...............(see Fig 121).

(b) Raw fibre, yellowish, thin-walled, walls very uneven in thickness; frequently weakly developed longitudinal ridges; just at the base the wall is very thick. *Vegetable down from Cochlospermum gossypium.*
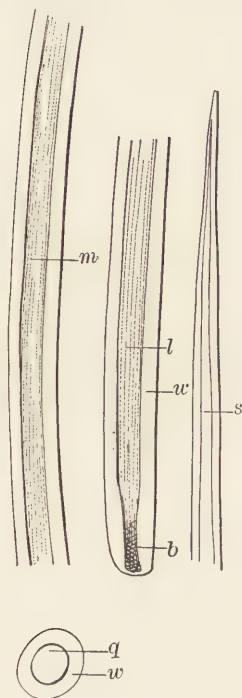
FIG. 121.—*Ochroma lagopus.* (×340.) (Höhnel.) *m*, middle part of fibre; *b*, base; *s*, pointed end; *l*, lumen; *q*, cross-section; *w*, cell-wall.

II. GENERAL TABLE FOR THE DETERMINATION OF THE VEGETABLE FIBRES.

Including cotton, as well as the more important fibres derived from bast or sclerenchymous tissues.

A. Fibres Colored Blue, Violet, or Greenish with Iodin and Sulphuric Acid.

(a) BAST-FIBRES AND COTTON. (Cotton, flax, hemp, sunn hemp, ramie, Roa fibre.)

I. The cross-sections become blue or violet with iodin and sulphuric acid; show no yellowish median layer; the lumen is often filled with a yellowish marrow.

1. *Cross-sections:* they occur either singly or in small groups; the single sections do not join over one another; are polygonal, and have sharp edges; iodin and sulphuric acid colors them blue or violet; they show closely packed, delicate layers; the lumen appears as a yellow point.

Longitudinal appearance: with iodin and sulphuric acid, quite blue; it appears transparent, quite uniformly thick; smooth or delicately marked; joints frequent; indications of dark lines running through, which are usually crossed; enlargements on the fibre, especially at the joints, frequent; the lumen appears as a narrow yellow line; the natural ends of the fibres are sharply pointed; length 4 to 66 mm., thickness 15 to 37 μ.

Linen or Flax.

2. *Cross-sections* single or very few in a group, loosely held together; polygonal or irregular, mostly flat, very large; colored blue or violet with iodin and sulphuric acid; stratification not noticeable; the lumen is large and irregular; frequently filled with a dark yellow marrow; radial fissures frequently apparent.

Longitudinal appearance: many of the fibres remarkably broad; the width of a single fibre very uneven; smooth or striped; very often ruptures in the wall; with iodin and sulphuric acid, blue or violet; the lumen readily seen; very broad, often containing a dark yellow marrow; joints noticeable; dark, transverse lines frequent, often crossing each other; the ends are relatively thick-walled and blunt; length 60 to 250 mm., thickness up to 80 μ . . . .*China grass, Ramie.*

3. *Cross-sections:* not many in the groups; polygonal; mostly with straight or slightly curved sides and blunt angles; the lumen is contracted lengthwise regularly; frequently contains a yellow marrow, many sections are surrounded by a thin, greenish-colored layer; not closely joined to one another. The sections often show very beautiful radial marks or fissures and concentric layers; the various layers are colored differently.

Longitudinal appearance, as with China grass; proportional dimensions similar. . . . .*Roa fibre.*

4. *Cross-sections* always isolated, rounded, various shapes, mostly kidney-shaped; with iodin and sulphuric acid, blue or violet; lumen contracted, line-shaped, often containing a yellowish marrow; no stratification.

Longitudinal appearance: fibres always separate; with iodin and sulphuric acid, a fine blue; streaked and twisted; lumen broad, distinct, frequently contains yellowish marrow; ends blunt; the entire fibre not soluble in concentrated sulphuric acid; coated with a very thin cuticle; length 10 to 60 mm., breadth 12 to 42 μ . . . .*Cotton.*

II. Cross-section blue or violet with iodin and sulphuric acid; polyhedral, rounded or irregular; always surrounded by a yellow median layer.

1. *Cross-sections* always in groups, with angles more or less rounded off, lying very close to one another; all of them sur-

rounded by a thin, yellowish median layer; the lumen is line-shaped, single or forked, often broad, with inturning edges, without marrow; good concentric stratification; the different strata being differently colored.

Longitudinal appearance: with iodin and sulphuric acid, blue, greenish, or dirty yellow; fibres irregular in thickness, frequently with appended portions of yellowish median layer; joints
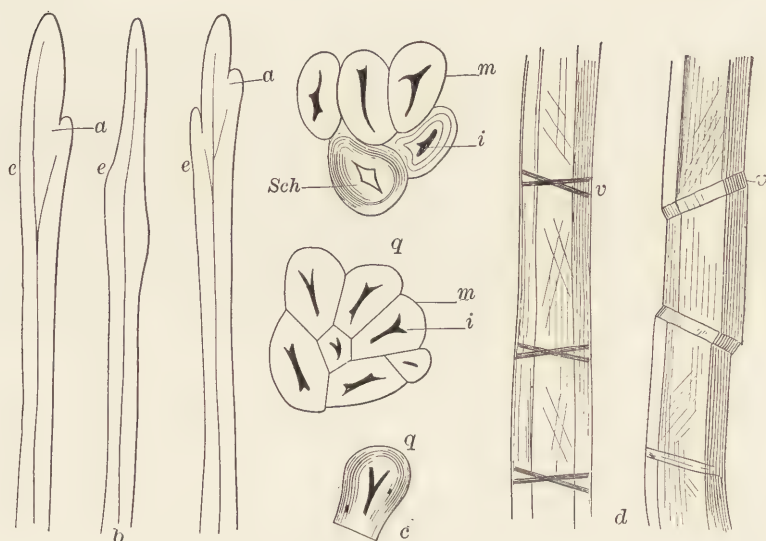
FIG. 122.—Hemp. (×340.) (Höhnel.) *b*, ends of fibres; *c*, cross-section; *d*, longitudinal view.

and transverse lines frequent; stripes very distinct; the lumen is not very apparent, but broader than linen; ends are broad, thick-walled, and blunt, often branched; length 5 to 55 mm., breadth 16 to 50 μ ....*Hemp* (see Fig. 122).

2. *Cross-sections* in large groups, lying very close together and touching; very similar to those of hemp; often crescent-shaped. Polygonal or oval, with lumen of varying size, frequently containing yellowish marrow; lumen usually not line-shaped, but irregular; a broad yellow median layer always present, from which the blue inner strata are easily distinguished; stratification very distinct, as with hemp.

Longitudinal appearance, as with hemp, except in dimensions, which are: length 4 to 12 mm., breadth 25 to 50 μ.

Sunn hemp.

(*b*) LEAF FIBRES. (With vascular tissue; without jointed structure. Esparto and pineapple fibre.)

FIG. 123.—Esparto-grass. (×340.) (Höhnel.) *s*, short sclerenchymous elements; *l*, cells; *f*, fibres; *h*, hairs; *e*, epidermal cells.

1. *Cross-sections* in large, compact, often crescent-shaped groups; very small; pale blue or violet with iodin and sulphuric acid; surrounded by a thick, shell-like network of median layer; rounded or polygonal; lumen like a point or streak; thick cuttings appear greenish or even yellow; frequently bundles of vascular tissue with one or two rows of thick, yellow-colored fibres.

Longitudinal appearance: Fibres slender, regular, very thick-walled, smooth; lumen often invisible, generally as a fine

line; ends are tapered with needle-like points; color with iodin and sulphuric acid, blue, often but slightly pronounced; frequently present short, thick, stiff, completely lignified fibres from vascular tissue; length 5 mm., breadth 6 μ.

<div align="right">*Pineapple fibre.*</div>

2. *Cross-sections* in groups; with iodin and sulphuric acid, mostly blue, though also yellow; often with pronounced stratification; the outer strata frequently yellow, while the inner are blue; rounded or oval, seldom straight-sided; lumen like a point.

Longitudinal appearance: the fibres are short; blue with iodin and sulphuric acid; thin, very firm, smooth, uniform in breadth; lumen yellow, line-shaped; ends are seldom pointed, mostly blunt or chiselled off, or forked; length 1.5 mm., breadth 12 μ..................................... *Esparto* (see Fig. 123).

B. Fibres Colored Yellow with Iodin and Sulphuric Acid.

(*a*) DICOTYLEDONOUS FIBRES. (Without vascular bundles; lumen showing remarkable contractions. Including jute, *Abelmoschus*, Gambo hemp, *Urena*, and Manila hemp; the latter sometimes shows vascular tissue.)

I. Cross-sections in groups; polygonal and straight-lined, with sharp angles; lumen round or oval, smooth, and without marrow; cross-sections with narrow median layers showing the same color as the inner strata with iodin and sulphuric acid; lengthwise appearance shows the lumen with contractions.

1. *Cross-sections* polygonal, straight-lined; lumen, in general, large, round, or oval.

Longitudinal appearance: fibres smooth, without joints or stripes; lumen distinctly visible; broad; with contractions; the ends always blunt and moderately thick; ends have wide lumen; length 1.5 to 5 mm., breadth 20 to 25 μ...................*Jute.*

2. *Cross-sections* in general somewhat smaller than jute; sides straight, with sharp angles; lumen frequently like a point or line, oval, occasionally pointed; not so large as with jute.

Longitudinal appearance: fibres quite even in thickness, smooth, with occasional joints or stripes; lumen narrow, irregular in thickness, contractions frequent; the ends are broad,

blunt, frequently thickened; length 1 to 1.6 mm., breadth 8 to 20 μ............*Pseudo-jute* or *Musk mallow* of *Abelmoschus*.

II. Cross-sections in groups, lying close together; polygonal, with sharp lines and sharp or rounded angles; lumen without marrow; the median layer is broad, and with iodin and sulphuric acid is colored perceptibly darker than the inner layer of cell-wall; the lumen in places is completely lacking.

1. *Cross-sections* more or less polygonal, with sharp or slightly rounded angles; the lumen is small, becoming broader and more oval as the section is more rounded; the median layer is broad, and is colored considerably darker than the cell-wall with iodin and sulphuric acid; stratification occasional and indistinct.

Longitudinal appearance: the fibres vary much in thickness; lumen generally narrow, with decided contractions, and in some parts totally absent; the broader fibres often striped; ends are blunt and generally thickened; length 2 to 6 mm., breadth 14 to 33 μ............*Gambo hemp*.

FIG. 124.—Pseudo-jute (*Urene sinuata*). ($\times$340.) (Höhnel.) *l*, longitudinal view; *v*, interruption of lumen; *e*, end with thick wall; *q*, cross-section; *m*, median layer; *L*, small lumen.

2. *Cross-sections* always in groups; small, polygonal, with sharp angles; lumen very small, appearing as a point or a short line.

Longitudinal appearance: occasionally jointed or striped; lumen with decided contractions, in some places altogether lacking; ends blunt and sometimes thickened; length 1.1 to 3.2 mm., breadth 9 to 24 μ.

Pseudo-jute from *Urena sinuata* (see Fig. 124).

(*b*) MONOCOTYLEDONOUS FIBRES. (Occurring as vascular bundles together with bast; the lumen exhibits no contractions;

in Manila hemp vascular bundles often lacking. Includes New
Zealand flax, Manila hemp, *Sánsevieria* or bowstring hemp, Pita
hemp, and Yucca fibre.)

I. Cross-sections generally rounded, occasionally polygonal;
the lumen is always rounded, without contractions longitudinally;
median layer indistinct, or only as a narrow line; vascular tissue
small in amount, or altogether lacking.

1. *Cross-sections* small, generally rounded, lying loosely sepa-
rated; very rounded angles; lumen small, round, or oval, without
marrow.

Longitudinal appearance: the fibres are stiff and thin;
the lumen is small but very distinct, and uniform in width; the
ends are pointed; no markings and no joints; length 5 to 15 mm.,
breadth 10 to 20 μ........................ *New Zealand flax.*

2. *Cross-sections* polygonal, with rounded angles, in loosely
adherent groups; lumen large and round, often containing yellow
marrow.

Longitudinal appearance: fibres uniform in diameter;
walls thinner than those of New Zealand flax; lumen large and
distinct; ends pointed or slightly rounded; silicious stegmata
adhering to the fibre-bundles and to be found in the ash as bead-
like strings, insoluble in hydrochloric acid; length 3 to 12 mm.,
diameter 16 to 32 μ.............................*Manila hemp.*

II. Cross-sections polygonal; lumen large and polygonal,
with angles quite sharp; median layer lacking or only in the form
of a thin line.

1. *Cross-sections* distinctly polygonal, often with blunt angles,
lying compactly together; lumen large and polygonal, with sharp
angles; no stratification in cell-wall.

Longitudinal appearance: fibres thin and smooth; lumen
large and distinct; ends pointed; length 1.5 to 6 mm., diameter
15 to 26 μ.....................................*Sansevieria fibre.*

2. *Cross-sections* polygonal, not many sections to a group, but
lying compactly together; angles slightly rounded; lumen not
very large, polygonal, often having blunt angles; besides the
bast-fibre sections are to be noticed some vascular bundles in the
form of large spirals.

Longitudinal appearance: fibres uniform in diameter; lumen not very large, but uniform; no structure; ends pointed and sometimes blunt; length 1.3 to 3.7 mm., diameter 15 to 24 μ.

Aloe hemp.

3. *Cross-sections* polygonal, with straight lines; angles sharp, though sometimes blunt; sections lie compactly together; lumen large and polygonal, though angles not so sharp.

Longitudinal appearance: fibres stiff, and often very wide towards the middle; lumen large; ends broad, thickened, and often forked; large, shining crystals to be found in the ash, which
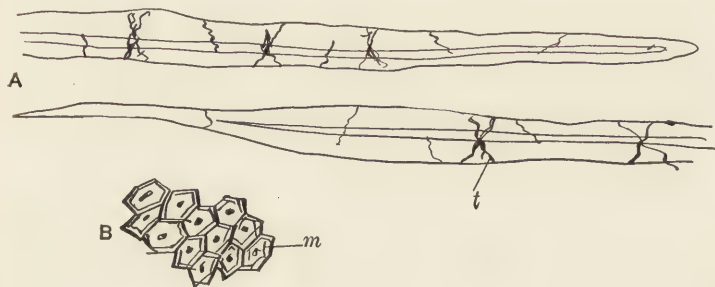
FIG. 125.—Yucca Fibre. ($\times$400.) *A*, longitudinal view; *B*, cross-section; *m*, median layer; *t*, transverse markings. (Micrograph by author.)

are derived from the chisel-shaped crystals of calcium oxalate clinging to the outside of the fibre; these crystals are often $\frac{1}{2}$ mm. in length; length of fibre 1 to 4 mm., diameter 20 to 32 μ.

Pita hemp.

III. Cross-sections polygonal and small, sides straight, with very sharp angles; lumen small, usually as a point or line-shaped; sections lie compactly together and are surrounded by a thick, distinct median layer.

1. *Cross-sections* as above.

Longitudinal appearance: fibres very narrow; lumen also very narrow; longitudinal ridges frequent; ends usually sharp-pointed; length 0.5 to 6 mm., diameter 10 to 29 μ.

Yucca fibre (see Fig. 125).

C. Analytical Review of the Chief Vegetable Fibres.

1. Those occurring as thick, fibrous bundles, also with vascular tissue (monocotyledonous fibres) ....(see 2).

Vascular tissue absent; sections and fibres always single; round or kidney-shaped by being pressed together; fibres with a thin external cuticle insoluble in concentrated sulphuric acid, and not swelling (vegetable hairs).........................(see 7).

Vascular tissue absent; the fibres are bundles of bast filaments; sections occurring two or more together (mostly true dicotyledonous fibres) ....(see 13).

2. Lumen very narrow, line-shaped, much thinner than the wall..(see 3).

Lumen in thickest fibres almost as wide, or even wider, than the wall; completely lignified....................(see 4).

3. Sections polygonal, sides straight, with sharp angles; completely lignified; diameter 10 to 20 μ.. *Yucca fibre* (see Fig. 125).

Sections rounded to polygonal; often flattened or egg-shaped; the inner strata at least not lignified; diameter 4 to 8 μ.
Pineapple fibre.

4. Thick, strongly silicified stegmata occurring at intervals on the fibre-bundles in short to long rows, sometimes but few; these are four-cornered, have serrated edges, and show a round, bright, transparent place in the middle; they are easily seen after the fibre has been macerated with chromic acid, and are about 30 μ in length; in the ash of fibres previously treated with nitric acid, they appear in the form of pearly strings, often quite long, and insoluble in hydrochloric acid; they are joined together lengthwise; the fibres are thick-walled, with fissure-like pores; 3 to 12 mm. long; the fibre-bundles are yellowish and lustrous.
Manila hemp.

Stegmata present, sometimes in small, sometimes in large quantities; they are lens-shaped, small (about 15 μ wide), and are fastened to the exterior fibres of the bundles by serrated edges; in the ash of the fibre they melt together in the form of indistinct globules; in the ash of fibres previously boiled in nitric acid they

appear as yeast-cells, joined together in round skeletons of silica; the fibres are often thin-walled, with numerous pores; 1 to 2 mm. in length; the raw fibres generally brown and rough......*Coir*.

Stegmata absent, hence the fibres are not accompanied by silicified elements.....................................(see 5).

5. Fibre-bundles covered externally at intervals with crystals of calcium oxalate, at times up to 0.5 mm. in length; lustrous, with quadrangular sections, chisel-shaped at the ends, hence they appear as thick, needle-shaped crystals; when present in large numbers these crystals occur in long rows which are frequently visible to the naked eye, and always easily recognizable under the microscope, especially in the ash. The fibre-bundles are mostly thick, and their outer fibres (as a result of their preparation) frequently contain fissures or are torn; thickness of the walls very uneven; fibres often much widened at the middle.

Pita hemp.

Without crystals, generally thin; in cross-section usually less than 100 fibres to a bundle; thickness of walls and lumen very uniform..(see 6).

6. Sections mostly round, not very compact; lumen usually thinner than the wall, but never a single line; in section round or oval; vascular tissue in but small amount.

New Zealand flax.

Sections, on one side at least, polygonal; section of lumen polygonal, with angles more or less sharp; generally as wide or wider than the wall; vascular tissue frequent.

Aloe hemp.

7. Fibres mostly rope-shaped, twisted, externally streaked, generally possessing fine granules or marked with little lines, therefore rough; thin to thick walls; cross-sections squeezed together, or round to kidney-shaped, hence the fibre has more or less the shape of a flat band; section of lumen more or less arched, line-shaped, frequently containing yellow marrow; consists of pure cellulose with the exception of the thin cuticle.

Cotton.

Fibres not twisted, smooth externally, and without longitudinal markings; fibres not flat, sections round; walls generally

very thin; sometimes, however, they are thick; lignified, scarcely swelling in ammoniacal copper oxide... *Vegetable down* ⎫
Vegetable silks ⎭ (see 8).

8. Fibres on the inside possess from 2 to 5 broad ridges, which at times are very noticeable, at others scarcely visible; they run lengthwise in the fibre, and in section are semicircular; on this account the walls appear unequal in thickness when viewed ongitudinally; the maximum thickness is about 35 μ.

Vegetable silks (see 9).

Fibres without ridges; maximum thickness mostly 30 to 35 μ................................*Vegetable down* (see 12).

9. Largest diameters 50 to 60 μ; length 3.5 to 4.5 cm..(see 10).
Largest diameters 35 to 45 μ; length 1.5 to 4 cm..(see 11).

10. Fibres contracted at the lower end, and directly above abruptly swelling, becoming 80 μ thick; the under portion of the swollen area contains numerous pore-canals; fibres feather-like or brush-like, arising from a straight shaft.

Vegetable silk from Sengal.

Contrary to the above the fibres originate from one point, like a fan; remarkably strong, curved backwards; very firm.

Vegetable silk from India.

Like the foregoing, but the fibre is stiff, straight, weak, and brittle...............................*Calotropis procera.*

11. Thickened ridges very noticeable; in the cross-sections often occurring in the form of a semicircle; bound together in a strictly reticulated manner.

Vegetable silk from Asclepias cornutii.

Thickened ridges indistinct, projecting but slightly in the cross-section.......*Vegetable silk from Asclepias curassavica.*

12. Raw fibre, yellowish; broadened at the lower end (up to 50 μ); also reticular thickening or transverse markings; wall 1 to 2 μ thick....................................*Bombax cotton.*

Raw fibre, brown; the lower end contracted and not showing reticulated thickenings; fibre almost altogether thin-walled, though just at the lower end very thick-walled.

Cochlospermum gossypium.

13. Thick fibre-bundles, whose outer surface contains at inter-

vals series of thick silicious plates, having sharp indented edges and a round, hollow space........*Manila hemp* (see under 4).

Silicious plates absent; lengthwise the lumen often exhibits remarkable contractions, while the wall is very uneven in thickness; at intervals, indeed the lumen is almost entirely interrupted; joints and transverse fissures along the fibre; transverse markings and lines, which appear somewhat like zones or knots, are completely lacking, or are very rare and indistinct; completely lignified, hence colored yellow with iodin and sulphuric acid...(see 14).

Silicious plates absent, also remarkable contractions of the lumen; thickness of the walls very uniform; joints and fissures along the fibre, transverse lines and markings frequent, hence the fibre often appears as if it contains swollen knots; unlignified, or only lignified on the external layer of membrane, hence lengthwise the fibre is colored blue with iodin and sulphuric acid or violet or green, or at the most colored yellow in places..(see 17).

14. Exterior layers of membrane narrow and showing the same coloration with iodin and sulphuric acid as the inner layers, hence the same as the entire cross-section; the lumen hardly ever completely interrupted..........................(see 15).

Median layer in sections wide; colored considerably darker with iodin and sulphuric acid; lumen often completely interrupted..(see 16).

15. Lumen in general large, diameter as wide or only a little narrower than the wall; in section round or oval, seldom as a point; no crystals of calcium oxalate...............*True jute.*

Lumen usually small, diameter much narrower than the thick wall in section frequently as a point; crystals of calcium oxalate of frequent occurrence (detected by ignition).

Pseudo-jute (Abelmoschus) (see Fig. 126).

16. Lumen almost always considerably smaller than the wall; ends usually very thick-walled and narrow; calcium oxalate crystals of frequent occurrence.

Pseudo-jute (Urena sinuata).

Lumen frequently as wide as or wider than the wall, mostly narrower however; ends broad and blunt........*Gambo hemp.*

17. The lumen in the middle portion of the fibre generally line-shaped, much narrower than the wall; ends never blunt, always sharply pointed; sections isolated or in small groups, regular in diameter, sharp-angled and straight-sided polygonals; without separate median layer; iodin and sulphuric acid colors the entire section blue or violet; the lumen in the cross-section is
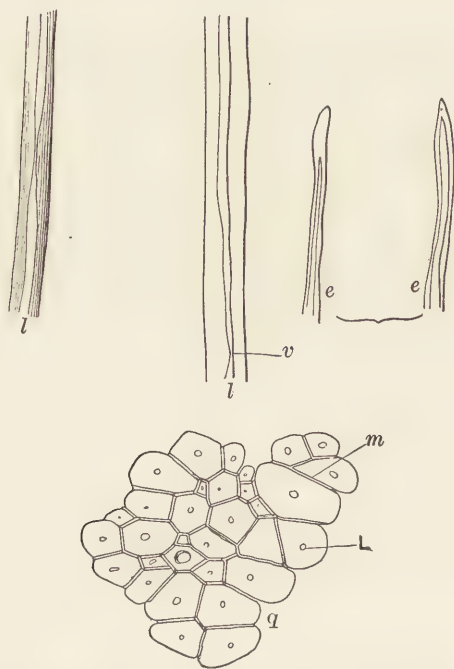
FIG. 126.—*Abelmoschus* Jute. (×325.) (Höhnel.) *l*, longitudinal view; *q*, cross-section, *e*, ends; *L*, small lumen; *v*, narrowing of lumen; *m*, median layer.

very small, or as a point, containing a marrow which is colored yellow with iodin and sulphuric acid.............*Linen or Flax.*

Lumen, at least in the central portion of the fibre, always much thicker than the walls; in section generally more or less flattened, narrow to broad, egg-shaped or oval. Fibre ends blunt, never sharply pointed; sections almost never sharp-angled polygonals, but more or less oval or elliptical, and with a rounded boundary. ....(see 18).

18. Breadth of fibre up to 80 μ; maximum length 15 to 60 mm.; sections always in compact groups, which often consist of many fibres, with thinner or thicker layers of membrane, which are colored yellow with iodin and sulphuric acid, hence the fibre is never colored a pure blue, but dirty blue to greenish, and in places yellow; ends often have side branches projecting......(see 19).

19. Lignified exterior membranes very thin; lumen in section narrow, very seldom broad, fissure-like or line-shaped, often branched, without marrow.............................*Hemp.*

Lignified exterior layers often as wide as the interior layers, or wider; the interior layers are often loosened in places from the exterior ones where they are thin; lumen in section scarcely ever narrow or fissure-shaped, but broad, oval, or long; often containing a yellowish marrow...........................*Sunn hemp.*

CHAPTER XVIII.

QUANTITATIVE ANALYSIS OF THE TEXTILE FIBRES.

1. Wool and Cotton Fabrics.—The finishing materials and coloring-matters should be removed as far as possible by boiling the sample to be examined first in a 1 per cent. solution of hydrochloric acid, then in a dilute solution of sodium carbonate (about a one-twentieth per cent. solution), and finally in water. A portion of the material is then dried at 100° C. for an hour (or until constant weight is obtained) and weighed; this weight will represent the actual amount of true fibre present in the sample, and the loss will correspond to moisture. Then steep for twelve hours in a mixture of equal parts of sulphuric acid and water, and mix with three volumes of alcohol and water; filter off the dissolved cotton and wash the residue of wool well with alcohol. Dry at 100° C., and weigh; this will give the amount of wool present.* The following example will illustrate this method:

	Grams.
Sample weighed.	3.62
After treatment with acid and alkali.	3.17
Finishing materials, etc.	0.45
After drying at 100° C.	2.77
Loss as water.	0.40
Wool left after treating with acid.	1.96
Cotton, by difference.	0.81

Hence the composition of this sample would be as follows:

	Per Cent.
Finishing materials.	12.43
Moisture.	11.05
Wool.	54.14
Cotton.	22.38
	100.00

* By this treatment the wool suffers a loss of about $2\frac{1}{2}$ per cent.

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Another, and perhaps a better, method for determining the relative amounts of wool and cotton in a mixed fabric or yarn, especially when the cotton is present in rather large proportion, is to remove the wool by treatment with a dilute boiling solution of caustic potash. The estimation is carried out in the following manner:

The sample to be tested is treated with hydrochloric acid and sodium carbonate solutions as before, in order to remove finishing materials, and after thorough washing is dried at 100° C. and weighed. This gives the weight of the dry fibres. The weighed sample is then boiled for twenty minutes in a 5 per cent. solution of caustic potash.* The residue is well washed in fresh water, and redried at 100° C. and weighed. The residue consists of cotton, the wool having been dissolved by the caustic potash.† If the residue becomes disintegrated and cannot be washed and dried as one piece, it should be collected on a tared filter (one which has been dried at 100° C. and weighed) and well washed with water, then dried at 100° C. and weighed. The tared weight of the filter subtracted from the latter will give the weight of the cotton particles.

Examples:

(*a*) Analysis of a cloth sample:

	Grams.
Weight of sample..................................	5.42
After treatment with acid and alkali.................	5.10
Finishing materials, etc........................	0.32
After drying at 100° C............................	4.26
Loss as water................................	0.84
Cotton left after boiling with caustic alkali............	2.82
Wool, by difference.............................	1.44

* It is not advisable to use caustic soda instead of caustic potash, as the results obtained are not as satisfactory.

† In case yarns are to be analyzed, the preliminary treatment should consist of a thorough scouring with soap. After drying in the air, the loss in weight should be recorded as grease and miscellaneous dirt. On then drying at 100° C. to constant weight, the loss will represent moisture, and the residue dry fibre. This is then analyzed as in the manner above described.

Hence the composition of this sample would be:

	Per Cent.
Finishing materials	5.98
Moisture	15.50
Cotton	52.03
Wool	26.49
	100.00

Since the cotton itself suffers a slight loss on boiling with caustic potash, it is customary, as a correction, to add to the cotton found 5 per cent. of its weight,* and to subtract a corresponding amount from that of the wool. On applying this correction the result of the above analysis would become:

	Per Cent.
Finishing materials	5.98
Moisture	15.50
Cotton	54.63
Wool	23.89
	100.00

Figured on the weight of the dry fibre, the relative amounts of the two fibres in the above samples would be:

	Per Cent.
Cotton	69.5
Wool	30.5
	100.0

Since, however, in making mixes, the dry weights of the fibres are not taken, we may assume the weight to include the normal amount of moisture held by each fibre. As the normal amount of moisture for cotton is about 8 per cent., and for wool about 16 per cent., we may approximate very closely to the true composition of this sample by adding to the dry weights of the fibres their respective amounts of moisture; the relative amounts of cotton and wool then become:

	Grams.
Weight of cotton found	2.82
Add 5 per cent. correction	0.14
	2.96

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* The author has found that the cotton will not lose, as a rule, more than 3 per cent.

This represents 92 per cent. of air-dry cotton.

	Grams.
Hence air-dry cotton would be.......................	3.22
Weight of wool found...........	1.44
Subtract correction for cotton.	0.14
	1.30

This represents 84 per cent. of air-dry wool.

	Grams.
Hence air-dry wool would be........................	1.54

Therefore the relative amounts of cotton and wool on this basis would be:

	Per Cent.
Cotton..	67.6
Wool....................................	32.4

(*b*) Analysis of a yarn:

	Grams.
Weight of sample....................................	5.65
Scoured in soap, washed, and air-dried...............	4.97
Grease, etc.	0.68
Dried at 100° C......................................	4.32
Loss as moisture.	0.65
Weight of filter-paper dried at 100° C.................	1.16
Weight of filter and residue of cotton dried at 100° C....	3.66
Weight of dry cotton............................	2.50
Add 5 per cent. correction...........................	2.62
Correct for moisture at 8 per cent....	2.85
Weight of dry wool by difference (with correction)......	1.70
Correct for moisture at 16 per cent....	2.02

Hence the composition of this yarn may be expressed as:

	Per Cent.
Grease, etc.	12.00
Moisture..	11.50
Cotton.......................	44.25
Wool...	32.25
	100.00

And the relative proportion of the two fibres would be as follows:

	Dry at 100° C.	Air-dry.
Cotton.............................	60.7	58.5
Wool..............................	39.3	41.5
		100.00

The following scheme for the analysis of a fabric containing wool and cotton is given by Herzfeld: *

(*a*) *Estimation of moisture.*—Five grams of the fabric are dried at 100° C. until the weight is constant. The loss indicates the amount of moisture present.

(*b*) *Estimation of cotton.*—Five grams of the fabric are boiled for $\frac{1}{4}$ hour with 100 cc. of a 0.1 per cent. solution of caustic soda, then washed with water and treated with lukewarm 10 per cent. caustic potash solution, until the wool fibres are completely dissolved, if necessary the liquid being raised to the boil. The residue is washed with water, then treated for $\frac{1}{4}$ hour with dilute hydrochloric acid,† then washed again with water, boiled for $\frac{1}{4}$ hour with distilled water, washed with alcohol and ether, and finally dried at 100° C. until constant weight is obtained. The residue is cotton.

(*c*) *Estimation of wool.*—Five grams of the cloth are boiled with 100 cc. of a dilute solution of soda-ash for $\frac{1}{4}$ hour, washed with water, and steeped for 2 hours in sulphuric acid of 58° Bé.,‡ then washed with water, and boiled for $\frac{1}{4}$ hour with water, and finally washed with alcohol and ether, and dried at 100° C., until constant weight is obtained. The residue is wool.

(*d*) *Dressing and dye* are found by difference.

When a rough, approximate analysis of a wool-cotton is desired, it will be sufficient only to weigh the sample, boil for fifteen minutes in a 5 per cent. solution of caustic potash, wash well in acidulated water, then in fresh water, and dry in the air. On reweighing, the amount of cotton will be ascertained, while

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* *Yarns and Textile Fabrics*, p. 145.

† The object of washing with dilute hydrochloric acid is to neutralize the excess of caustic alkali in the fibre, so that it may be more readily removed, as caustic alkali remains in the fibre very pertinaciously.

‡ Acid of this strength is somewhat too strong, as it will decompose the wool to a considerable extent. It is not safe to employ sulphuric acid of greater strength than one part of acid to one part of water by volume.

the loss in weight will represent the amount of wool. Results attained by this process are usually sufficiently accurate to give one a practical idea of the approximate relative amounts of wool and cotton present in a sample of mixed goods.

Another method for the separation of wool from cotton in their quantitative estimation is treatment of the mixed fibres with an ammoniacal solution of copper oxide, whereby the cotton is dissolved; and after washing and drying, the residue of wool is weighed. This method, however, is not very satisfactory, as it is difficult, in the first place, to obtain a complete and thorough solution of the cotton; and in the second place, the wool will be considerably affected by this treatment and more or less decomposed. Consequently the results obtained by this method are not very accurate, and it cannot be recommended.

2. Wool and Silk.—Silk is soluble in strong hydrochloric acid, whereas wool is not soluble in this reagent to any extent. Hence this method may be utilized for the quantitative estimation of the two fibres when occurring together. The sample is first treated with acid and alkali in the manner already described in order to remove foreign materials other than actual fibre. It is then dried and weighed; then immersed in cold concentrated hydrochloric acid (about 40 per cent. strength). The silk dissolves almost immediately. The residue is collected, washed thoroughly, dried again, and weighed. The loss in weight represents silk, while the weight of the residue represents wool. Another method, and one which is very satisfactory, is to dissolve the silk by treatment with an ammoniacal solution of nickel oxide, in which reagent the silk is very readily soluble even in the cold. It only requires a treatment of about two minutes to completely dissolve the silk in most silk fabrics other than plush. Richardson * found that by this treatment cotton lost only 0.45 per cent. in weight and wool only 0.33 per cent. As silk in plush goods and similar fabrics is much more difficult to dissolve, it is recommended to boil such material with the nickel solution for ten minutes under a reflux condenser. By this treatment cotton will

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* *Jour. Soc. Chem. Ind.*, vol. 12, p. 430.

lose only 0.8 per cent. in weight. The nickel solution is best prepared by dissolving 25 gms. of crystallized nickel sulphate in 80 cc. of water; add 36 cc. of a 20 per cent. solution of caustic soda, carefully neutralizing any excess of alkali with dilute sulphuric acid. The precipitate of nickel hydroxide is then dissolved in 125 cc. of strong ammonia, and the solution diluted to 250 cc. with water. Instead of the above reagent, a boiling solution of basic zinc chloride may be employed for the purpose of dissolving the silk. This latter solution is obtained by heating together 1000 parts of zinc chloride, 850 parts of water, and 40 parts of zinc oxide until complete solution is effected. Richardson recommends that the sample to be examined should be plunged two or three times into the boiling solution of zinc chloride, care being taken that the total time of immersion does not exceed one minute. The zinc chloride solution should be sufficiently basic and concentrated in order to obtain good results. Under the best conditions, cotton loses about 0.5 per cent. in weight, and wool from 1.5 to 2.0 per cent.*

3. Silk and Cotton.—The methods given above for separating silk from wool may also be used for the separation and quantitative determination of silk in fabrics containing this fibre in conjunction with cotton.

Another method for separating silk from cotton is by the use of an alkaline solution of copper and glycerol, which serves as an excellent solvent for the silk. The reagent is prepared as follows: Dissolve 16 gms. of copper sulphate in 150 cc. of water, with the addition of 10 gms. of glycerol; then gradually add a solution of caustic soda until the precipitate of copper hydrate which is at first formed just redissolves. This solution readily dissolves silk, but is said not to affect either wool or the vegetable fibres. Richardson, however, has found that cotton heated with this solution for twenty minutes (the time necessary to dissolve silk in plush) lost from 1 to 1.5 per cent. in weight and became friable

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* The chief difficulty attached to the use of the zinc chloride solution is that it requires a long and tedious washing to remove all of the zinc salt from the residual fibres. It is best to wash with water acidulated with hydrochloric or acetic acid.

and dusty on drying; while woolen fabrics lost from 9 to 16 per cent. in weight. Hence the reagent would be useless in the analysis of fabrics containing wool.

4. Wool, Cotton, and Silk.—Samples of shoddy frequently contain all three of these fibres present in greater or lesser amount, and often it is desirable to know at least the approximate amounts of each fibre in the mixture. A method of procedure recommended is the following: A weighed sample of the material is boiled for thirty minutes in a 1 per cent. solution of hydrochloric acid, washed, and then boiled for thirty minutes in a 0.05 per cent. solution of soda-ash. This preliminary operation is similar to that above described in the preceding analyses, and is for the purpose of freeing the fibres as far as possible from extraneous foreign matter. After thorough washing and air-drying, the weight of the sample is again taken, and the loss will represent *miscellaneous foreign matter.* The sample is then dried at 100° C. to constant weight; the loss in weight will represent *moisture.* The sample is then divided into two weighed portions; the first is treated for five minutes with a boiling solution of basic zinc chloride prepared as above described, washed thoroughly with acidulated water, then with fresh water, and dried at 100° C. again. The loss in weight will represent the amount of silk present. The second portion of the sample is boiled for ten minutes in a 5 per cent. solution of caustic potash; washed thoroughly, dried at 100° C. and weighed. This weight, with a correction of 5 per cent. added to it, will represent the amount of cotton present. The amount of wool is obtained by taking the difference between the total weight of the combined fibres and the sum of the weights of the silk and cotton.

Example:

	Grams.
Sample of loose shoddy weighed......................	5.06
Treated with acid and alkali, and air-dried..............	4.23
Loss as foreign matter.........................	0.83
Dried at 100° C..................................	3.62
Loss as moisture..............................	0.61

Divided into two portions:

		Grams.
(a)	weighed.....................................	1.95
(b)	weighed......................................	1.67
(a)	treated with zinc chloride.	1.73
	Loss as silk.	0.22
(b)	treated with caustic potash, residue as cotton.	0.34
	Loss as wool.	1.33

Hence the composition of this sample on the basis of **dry** fibre would be:

	Per Cent.
Silk..	11.3
Cotton..	21.5
Wool.	67.2
	100.0

Von Remont gives the following method for analyzing fabrics containing a mixture of silk, wool, and cotton. Four quantities (A,B,C,D) of 2 gms. each of the air-dried material are weighed out. Portion A is kept aside, and each of the other three is boiled for fifteen minutes in 200 cc. of water containing 3 per cent. of hydrochloric acid. The liquid is decanted, and the boiling repeated with more dilute acid. This treatment removes the size and the major portion of the coloring-matter. Cotton is nearly always decolorized quite rapidly, wool not so readily, and silk but imperfectly, especially with black-dyed fabrics. The samples should be well washed and squeezed in order to remove the acid liquor. Portion B is set aside. Portions C and D are then placed for two minutes in a boiling solution of basic zinc chloride (of 1.72 sp. gr., and prepared as above described), which dissolves any silk present. They are then washed with water containing 1 per cent. of hydrochloric acid, and again with pure water, until the washings no longer show the presence of zinc. Portion C is squeezed and set aside. Portion D is boiled gently for fifteen minutes with 60 to 80 cc. of caustic soda solution (1.02 sp. gr.) in order to remove any wool. The sample is then carefully washed with water. The four portions are next dried for an hour at 100° C., and then left exposed to the air for ten hours in order to allow them to absorb the normal amount of hygro-

scopic moisture. The four samples are then weighed, and calling a, b, c, and d their respective weights, we shall have

$$a - b = \text{dye and finishing material;}$$
$$b - c = \text{silk;}$$
$$c - d = \text{wool;}$$
$$d = \text{cotton (or vegetable fibre).}$$

This method is open to objections, as the plan of using air-dried material, then drying at 100° C., and subsequently exposing to the air again before reweighing, is liable to give very erroneous results. Richardson recommends that the samples should be thoroughly dried at 100° C. before being weighed out, and the treated portions should subsequently be dried at the same temperature before weighing. In order to prevent the sample from absorbing moisture during weighing, it is best to use a weighing-bott'e for holding the dried fibre. The sample before drying is placed in a weighing-bottle (the weight of which has been ascertained previously) and heated in an air-oven at 100° C. for the time specified, during which the cover of the weighing-bottle is removed. After the drying process is completed the stopper is replaced in the weighing-bottle; the latter is taken from the oven, allowed to cool, and is then weighed. The difference between this weight and the weight of the empty bott'e will give the amount of dry fibre.

Treatment with a boiling solution of 3 per cent. hydrochloric acid for the purpose of removing finishing materials is rather too severe, as the acid will act on the wool and the cotton, sometimes causing considerable error. Boiling with a 1 per cent. solution of acid for ten minutes is to be preferred.

The following is given as a practical method to determine if shoddy contains cotton and silk fibres: Boil 10 gms. of the shoddy to be tes ed. for one hour in 400 cc. of water containing 0.8 gm. of alum, 0.3 gm. of tartar; 1 cc. of hydrochloric acid, 0.1 gm. of chrome, and 0.05 gm. of bluestone. Rinse and dye with 0.3 gm. of logwood extract. Rinse and dry. The undyed fibres are then picked out and examined; cotton will remain white, while. silk will be colored a dingy red.

The analysis of heavy pile fabrics containing a mixture of fibres is especially difficult unless the fabric is disintegrated. In the analysis of plush for the amount of silk present, Richardson suggests treating the sample with a boiling solution of basic zinc chloride in the manner previously described; but when silk is to be determined in light fabrics (especially in the presence of wool), it is best to treat the sample for one to three minutes with a cold solution of ammoniacal nickel oxide. He gives the following comparison of results in the analysis of a sample of plush, using the three different methods for dissolving the silk:

	By Solution of Ammoniacal Nickel Oxide.	By Solution of Basic Zinc Chloride.	By Copper-glycerol Reagent.
Moisture and finish.............	11.34	11.00	10.04
Silk............................	45.60	45.00	47.06
Cotton.	43.60	44.00	42.90

Samples of plush with hard cotton backs may best be analyzed by successive treatment with acid and copper-glycerol reagent. On other cotton material, however, this method is not suitable; nor is it to be used in the presence of wool, as this fibre is considerably dissolved by the copper-glycerol reagent.

The following table by Richardson shows a comparison of the three methods employed for dissolving silk:

Fibre.	Actually Present.	Percentage Obtained by		
		Ammoniacal Nickel Oxide.	Basic Zinc Chloride.	Copper-glycerol Reagent.
Silk.	5.84	5.92	5.52	18.80
Wool.	76.31	76.58	80.08	64.05
Cotton.	17.85	17.50	14.40	17.15

The ammoniacal nickel oxide solution appears to give the best result; hence, in analyzing a sample containing silk, wool, and cotton, it is best to first remove the silk by means of this reagent. The insoluble residue left after this treatment is boiled with a 1 per cent. solution of hydrochloric acid, washed well in fresh water, and then boiled for five to ten minutes in a 2 per cent.

solution of caustic soda, which is sufficient to completely remove the wool without materially affecting the cotton.

From experiments conducted at the Philadelphia Textile School * the following comparative results have been obtained in the analysis of textile materials by the different methods suggested.

(*a*) Analysis of wool-cotton mixture:

Fibre.	Dissolving Wool by Caustic Potash.		Dissolving Cotton by Sulphuric Acid.	
	Theoret.	Found.	Theoret.	Found.
Cotton................................	56.7	55.2	63.7	64.2
Wool................................	43.3	44.8	36.3	35.8

(*b*) Analysis of wool-silk mixture:

Fibre.	With Hydrochloric Acid.		With Ammoniacal Nickel Oxide.		With Basic Zinc Chloride.	
	Theoret.	Found.	Theoret.	Found.	Theoret.	Found.
Wool................	76.6	76.24	78.5	77.3	81.7	71.5
Silk................	23.4	23.76	21.5	22.7	18.3	28.5

(*c*) Analysis of cotton-silk mixture:

Fibre.	With Hydrochloric Acid.		With Ammoniacal Nickel Oxide.		With Basic Zinc Chloride.	
	Theoret.	Found.	Theoret.	Found.	Theoret.	Found.
Cotton...............	70.	67.5	65.12	64.42	71.11	70.13
Silk................	30.	32.5	34.88	35.52	28.89	29.87

(*d*) Analysis of wool-cotton-silk mixture:

Fibre.	Silk by Ammoniacal Nickel Oxide; Wool by Caustic Potash.		Silk by Ammoniacal Nickel Oxide; Cotton by Sulphuric Acid.	
	Theoret.	Found.	Theoret.	Found.
Wool................................	41.2	42.1	41.	39.
Cotton............................	42.7	41.6	48.1	49.2
Silk................................	16.1	17.3	10.9	11.8

* See Collingwood, *Textile World Record*, vol. 29, pp. 874, 1193.

Fibre.	Silk by Hydrochloric Acid; Wool by Caustic Potash.		Silk by Hydrochloric Acid; Cotton by Sulphuric Acid.	
	Theoret.	Found.	Theoret.	Found.
Wool.	38.9	39.4	28.6	24.
Cotton.	42.2	38.	47.7	48.8
Silk.	18.9	22.6	23.7	27.2

Fibre.	Silk by Basic Zinc Chloride; Wool by Caustic Potash.		Silk by Basic Zinc Chloride; Cotton by Sulphuric Acid.	
	Theoret.	Found.	Theoret.	Found.
Wool.	59.	57.5	63.5	61.6
Cotton.	26.3	24.4	19.7	20.
Silk.	14.7	18.1	16.8	18.4

From a consideration of these results it would appear that in the analysis of wool-cotton mixtures the rapidity with which the caustic potash dissolves the wool gives this method a slight preference over the somewhat slower one of destroying the cotton by treatment with sulphuric acid. In the analysis of wool-silk materials the treatment with hydrochloric acid is slightly better than by the use of ammoniacal nickel oxide. The latter reagent, however, is the better to use for dissolving the silk from cotton-silk mixtures, as the cotton is too readily attacked by the concentrated hydrochloric acid. In the analysis of wool-cotton-silk mixtures the only proper reagent to employ for dissolving the silk is the solution of ammoniacal nickel oxide. Though the use of this reagent is rather slow compared with the others, it is thorough, and its action on the other two fibres is but slight.

The following table shows the corrections to be applied in the calculations of results, by reason of the action of the different reagents on the fibre which is not to be dissolved:

Separation of—
    (1) *Wool-cotton mixtures:*
        (*a*) Wool dissolved by caustic potash; correc-
            tion for loss of cotton. . . . . 3.0 per cent.

(b) Cotton dissolved by sulphuric acid; cor-
rection for loss of wool. . . . . 2.5 per cent.

(2) *Wool-silk mixtures:*

(a) Silk dissolved by hydrochloric acid; cor-
rection for loss of wool. . . . . 0.5 " "

(b) Silk dissolved by ammoniacal nickel oxide;
correction for loss of wool. . . . . 1.5 " "

(c) Silk dissolved by basic zinc chloride; cor-
rection for loss of wool. . . . . 2.0 " "

(3) *Cotton-silk mixtures:*

(a) Silk dissolved by hydrochloric acid; cor-
rection for loss of cotton. . . . . 4.0 " "

(b) Silk dissolved by ammoniacal nickel oxide;
correction for loss of cotton. . . . . 1.0 " "

(c) Silk dissolved by basic zinc chloride; cor-
rection for loss of cotton. . . . . 1.5 " "

Allen * also recommends the ammoniacal nickel solution for
use in dissolving silk from a mixture of fibres. His method of
analyzing a textile sample is as follows: The yarn or fabric is cut
up very fine with a pair of scissors, and thoroughly dried at 100° C.
One gram of the material thus prepared is treated with 40 cc. of
the cold ammoniacal nickel oxide solution for two minutes. The
liquid is then filtered, and the residue, consisting of wool and
cotton, is digested for two or three minutes in a boiling solution
of 1 per cent. hydrochloric acid. It is then washed free from
acid, dried at 100° C., and weighed. To separate the wool from
the cotton the residue is boiled with about 50 cc. of a 1 per cent.
solution of caustic potash for ten minutes, and the solution fil-
tered. The residue, consisting of cotton, is washed free from
alkali, dried at 100° C., and weighed.

To remove gum and weighting materials from goods contain-
ing silk, Richardson recommends treatment of the sample with a
cold 2 per cent. solution of caustic potash; this not only removes
any gum, but also decomposes any Prussian blue that may be
present (as a bottom under the black dye), so that the iron may

* *Commer. Org. Anal.*, vol. 4, p. 523.

be more easily removed by subsequent treatment with a 1 per cent. solution of hydrochloric acid. Metallic mordants, however, are difficult to remove in this manner, and at best they dissolve only imperfectly; it is best to calculate their amounts from the quantity of ash left after the ignition of the sample.

Oily matter (and also certain dyes) may be best removed by boiling successively with methylated spirits and ether. By evaporation of the solution so obtained the amount of oil and fat may be directly determined.

Höhnel recommends the use of a semi-saturated solution of chromic acid (see p. 128) for the quantitative separation of mixtures containing wool, cotton, flax, true silk, and tussah silk. On boiling such a mixture of fibres in this solution for one minute, the wool and true silk will be completely dissolved, leaving as a residue the cotton, flax, and tussah silk.

Other methods given by Höhnel for the quantitative analysis of fabrics containing mixtures of the fibres mentioned above are as follows:

(*a*) Any true silk is first removed by boiling for half a minute in concentrated hydrochloric acid; tussah silk is next removed by a longer boiling in the acid (three minutes); the residue, consisting of wool and vegetable fibres, is further separated in the usual manner by boiling in caustic potash solution.

(*b*) The fabric is first boiled in caustic potash solution, which dissolves the wool and the true silk, and leaves as a residue (*A*) tussah silk and vegetable fibre. A second sample is boiled for three minutes with concentrated hydrochloric acid, which dissolves both varieties of silk and leaves as a residue (*B*) wool and vegetable fibre. Residue *A* is then boiled three minutes with concentrated hydrochloric acid, which dissolves the tussah silk and leaves the cotton as a final residue. By subtracting this amount from residue *B* the amount of wool is obtained.

(*c*) A sample of the fabric is boiled for one minute in a semi-saturated solution of chromic acid, which dissolves the true silk and the wool, leaving as a residue the tussah silk and vegetable fibre. From this residue the tussah silk is removed by boiling for three minutes in concentrated hydrochloric acid, leaving the

vegetable fibre as a final residue. A second sample is boiled for three minutes in concentrated hydrochloric acid, which dissolves the silks and leaves the wool and vegetable fibre as a residue. From this the amount of wool can be obtained either by boiling in caustic potash solution, or by subtracting the cotton previously estimated. Finally, the amount of true silk may be found by subtracting the sum of the other constituents from the total in the original sample.

5. Analysis of Weighting in Silk Fabrics.—The practice of adding to the weight of silk in the dyeing and finishing operations has become so common that it is frequently desirable to ascertain in a sample of silk goods the amount of true fibre present and the amount and character of weighting. Black-dyed silk is especially liable to contain a very large amount of weighting materials; sometimes the degree of weighting may reach as high as 400 per cent. or even more. Colored silks are usually not weighted to such a great extent, but they will frequently be found to also contain considerable adulteration. Black-dyed silks are mostly loaded with Prussian blue and iron tannate, the latter being obtained by immersing the silk in a solution of pyrolignite or nitrate of iron, and subsequently in a solution of cutch or other tannin. Colored silks are principally weighted with tin phosphate obtained by treating the material with solutions of tin perchloride and sodium phosphate. Sometimes light-colored silks are also weighted with sugar, magnesium chloride, etc. Such materials are soluble in warm water, and hence their use is easily detected.

A convenient test which is frequently applicable to detect weighting is to ignite the silk fibre; if it is heavily weighted it will not inflame, but gradually smoulder away and leave a coherent ash retaining the original form of the fibre.

In general the substances which may be present as weighting materials are iron, as ferrocyanide or tannate; tin, as tannate, tungstate, phosphate, silicate, or hydroxide; chromium compounds; the sulphates or chlorides of sodium, magnesium, and barium; organic matters, such as sugar, glucose, gelatin, tannins, etc.

The following method for the qualitative analysis of weighting materials on silk has been recommended by Silbermann: * Substances that are easily soluble, such as sugar, glucose, glycerol, magnesium salts, etc., are estimated directly by boiling the silk with water and testing the extract with Fehling's solution, etc.† From 2 to 3 gms. of the silk are ignited and the ash is tested for tin (which may be present in the fibre as basic chloride and stannic acid), chromium, iron, etc.‡ Fatty matters, wax,

* *Chem. Zeit.*, vol. 18, p. 744.

† Fehling's reagent is an alkaline solution of copper sulphate containing potassium tartrate. It is prepared in the following manner: 34.639 gms. of pure crystallized copper sulphate are dissolved in about 250 cc. of water; 173 gms. of Rochelle salt (sodium potassium tartrate) are dissolved in the same quantity of water; 60 gms. of caustic soda are similarly dissolved. The three solutions are then mixed, and the mixture diluted to 1000 cc. with water. The reagent is employed as follows: 10 cc. of the solution are diluted with 40 cc. of water and brought to a boil; there is then added a portion of the solution to be tested for sugar (or glucose) which has previously been boiled with a small quantity of dilute hydrochloric acid. If sugar is present, the Fehling's solution will be decolorized and a bright-red precipitate of cuprous oxide will be thrown down. This test may be made quantitative by using a known quantity of sugar solution, filtering off the cuprous oxide, igniting, and finally weighing as copper oxide (CuO). In order to determine the amount of sugar (or glucose) corresponding to this latter, reference should be made to tables constructed by Allihn showing the proper equivalents of sugar and glucose for the amounts of copper oxide determined.

‡ These metals may be tested for in the ash in the following manner: Moisten with a few drops of nitric acid and re-ignite in order to be certain that all carbon is removed. Treat the residue with eight to ten drops of strong sulphuric acid; and gently heat until fumes are evolved; allow to cool and boil with water, dilute to about 100 cc. with water, and then pass hydrogen sulphide gas through the liquid; filter, and examine the solution and precipitate as follows: The aqueous solution may contain zinc or iron; add a few drops of bromin water to remove excess of hydrogen sulphide and to oxidize any iron present to the ferric condition; boil, then add ammonia in slight excess; boil again, and filter; if there is a precipitate, it may contain iron; if so, it should be brown in color; dissolve in a little hydrochloric acid and add a few drops of a solution of potassium ferrocyanide; a blue color will confirm the presence of iron. The filtrate, which may contain zinc, should be heated to the boil, and a few drops of potassium ferrocyanide solution added; a white precipitate will indicate zinc. The original precipitate produced by the treatment with hydrogen sulphide is next examined. This may contain lead, tin, or copper; it is fused for ten minutes in a porcelain crucible with 2 gms. of a mixture of potash and soda ash together with 1 gm. of sulphur. On cooling, the mass is boiled with water and filtered. The residue may contain lead and copper; it is boiled with strong hydrochloric

and paraffin are detected by extraction with ether or benzene.*
The silk is soaked in warm dilute hydrochloric acid (1:2); if
the fibre is almost decolorized by this treatment, only a slight
yellow tint remaining, whilst the solution assumes a deep brown-
ish color not changed to violet by addition of lime-water, it is
safe to conclude that the silk has been weighted by alternate
passages through baths of iron salts and tannin. The yellow
color of the fibre is due to a residuum of tannin, and the precise
shade (from greenish to brownish yellow) enables some idea to
be formed as to the nature of the tanning material used (sumac,
divi-divi, cutch, etc.). Decolorization of the fibre, the acid
extract being pink, and changing to violet by lime-water, indi-
cates a logwood black. If the fibre retain a deep greenish tint
and the solution be yellow and unaffected by lime-water, the
black is dyed on a bottom of Prussian blue. If the latter has
been produced during the final stage of dyeing, this will be shown
by its solubility in the acid. A green fibre and pink solution,
changing to violet on addition of lime-water, indicate a logwood
black dyed on a bottom of Berlin blue. In the hydrochloric

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acid, and a few drops of bromin water are added for the purpose of completely
oxidizing any copper sulphide present; filter if necessary, and add to the filtrate
an excess of ammonia, when a blue color will indicate presence of copper. Acid-
ulate the liquid with acetic acid and divide into two portions: to the first add a few
drops of a solution of potassium bichromate; a yellow precipitate will confirm
the presence of lead; to the other add a few drops of a solution of potassium
ferrocyanide, when a brown precipitate or coloration will indicate presence of
copper. The filtrate from the residue after the above fusion is acidulated with
acetic acid, when a yellow precipitate of stannic sulphide will indicate the pres-
ence of tin. The latter test may be confirmed by dissolving the precipitate of
stannic sulphide in hydrochloric acid and bromin water. The filtered solution
is then boiled with small pieces of metallic iron to reduce the tin; the liquid is
diluted and filtered and a drop of mercuric chloride solution is added, when a white
or gray turbidity will be produced if tin is present.

* Japan tram silk is frequently weighted with fatty substances. The normal
amount of fat in raw silk never exceeds 0.06 per cent. A direct determination
of the fatty matters may be made by treating 5 gms. of the silk sample in a
stoppered flask with pure benzene three or four times successively, using about
60 cc. of the solvent each time and allowing it to act from two to four hours with
frequent shaking. The several portions of benzene are brought together and
evaporated to dryness in a tared dish and the fatty residue is weighed. Another
method is to extract with ether in a Soxhlet apparatus.

acid solution, such metals as lead, tin, iron, chromium, and aluminium may be determined. Blacks produced by artificial dyes on a bottom of iron-tannin or iron-blue-tannin may be recognized by the coloration imparted to acid and caustic soda solutions. With blacks produced solely with coal-tar dyes, treatment with a hydrochloric acid solution of stannous chloride does not affect anilin and alizarin blacks; naphthol black is changed to reddish brown, and wool black becomes yellowish brown. Tannin materials in general may be extracted by alkalies, and subsequently precipitated and distinguished by ferric acetate. To remove the whole of the weighting material and the dye, the silk should be boiled with acid potassium oxalate, washed with dilute hydrochloric acid, and finally treated with soda solution. When iron and tin are both present in the fibre, it is best to first extract the tin by treatment with a solution of sodium sulphide.*

Vignon has proposed using the specific gravity of the silk sample as a means of determining the proportion of weighting materials present; but this method cannot be recommended as being at all practical, as the specific gravity of the weighting materials themselves would have to be known. The specific gravity of the silk may readily be determined as follows: A small sample is weighed as usual in the air; it is then suspended in benzene and the weight again taken. The difference between the two weighings will give the loss of weight in benzene; this loss divided into the original weight in air and multiplied by the density of the benzene will give the specific gravity of the silk. The specific gravity of silk and of other fibres determined in this way is as follows:

Silk, raw	1.30 to 1.37
Silk, boiled-off	1.25
Wool	1.28 to 1.33
Cotton	1.50 to 1.55
Mohair	1.30
Hemp	1.48
Ramie	1.51 to 1.52
Linen	1.50
Jute	1.48

* Persoz recommends in testing for tin weighting on dark-colored and black silks to boil the sample for a few minutes in concentrated hydrochloric acid. Then dilute and filter the acid, and pass hydrogen sulphide into it, when a yellow precipitate (SnS) would indicate the presence of tin.

For the examination of white silk Allen recommends the following: * (1) The total *soluble weighting materials* are determined by treating a known weight of the sample four to five times with hot water, redrying, and weighing. As the hygroscopic character of silk is very variable, it is best to employ a blank sample of a standard silk, and after redrying until the blank sample has regained its normal weight the test sample is weighed, and the loss represents the matters soluble in water. In the solution, after suitable evaporation, *glucose* may be determined directly by means of Fehling's solution (see p. 394), and *cane-sugar* after inversion by boiling with dilute hydrochloric acid. *Sulphates* and *chlorides* and *magnesium* † may be detected and determined as usual. *Stannic oxide* (if the silk has been weighted with tin compounds) will be left as a white residue on igniting a sample of the silk in a porcelain crucible. If much tin is present, the silk will burn with difficulty, and the ash will retain the shape of the original silk. The weight of the ash (assuming it to be wholly stannic oxide, SnO_2) may be calculated to the form in which the tin exists in the weighted silk (as metastannic acid, $SnO_2.H_2O$) by multiplying it by the factor 1.12.

Silbermann ‡ recommends for the analysis of white silk the following procedure: A weighed portion of the silk is boiled with dilute hydrochloric acid to dissolve any tannin lakes of tin or other metals, and in the solution tannin is tested for by the addition of an excess of sodium acetate and ferric chloride. If tannin

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* *Commer. Org. Anal.*, vol. 4, p. 527.

† Sulphates are detected by taking a small portion of the solution in a test-tube, adding a few drops of dilute hydrochloric acid and then a few drops of a solution of barium chloride; the production of a white precipitate indicates the presence of sulphates. Chlorides are detected by adding a drop of nitric acid to a test portion of the solution, and then a few drops of a solution of silver nitrate; a white precipitate will indicate the presence of chlorides. Magnesium is detected by adding to the test portion of the solution a few drops of ammonia followed by a solution of sodium phosphate; the formation of a white precipitate indicates the presence of magnesium. These tests may be made quantitative by taking definite aliquot portions of the solution, collecting the precipitates produced, and after ignition in a porcelain crucible weighing as barium sulphate, $BaSO_4$, silver chloride, $AgCl$, and magnesium pyrophosphate, $Mg_2P_2O_7$, respectively.

‡ *Chem. Zeit.*, vol. 20, p. 472.

lakes are present, the determination of the weighting materials consists in: (1) precipitation of the tannin from the aqueous solution with gelatin; (2) estimation of the tannin in this precipitate, and of sugar, etc., in the filtrate; (3) successive treatment of the silk with dilute hydrochloric acid and sodium carbonate, and precipitation of tannin from both solutions by means of gelatin; (4) ignition of the silk and determination of metallic weighting. If the ash is not completely soluble in hot moderately concentrated hydrochloric acid, it may contain barium sulphate or silica. To calculate the percentage of weighting material, W, in the silk examined, Silbermann employs the following formula, in which a is the weight of the sample before treatment, b the weight after extraction with water, p the stannic oxide left on ignition, and d the loss in weight during the boiling of the fibre itself. This is taken at 20 to 25 for boiled-off silk, 5 to 9 for souple silk, and 0 to 2 for écru.

$$W = \frac{a(100-d)}{b-1.13p} - 100.$$

The detection of tin or aluminium compounds in the weighting of white silk may be carried out by dyeing a sample of the silk with alizarin in the presence of chalk, then rinsing and soaping. Unweighted silk will retain only a pink color; if weighted with tin, the color will be orange, and if weighted with aluminium, the color will be red.

Dark-colored and black silks may contain hydroxides of tin, iron, and chromium, fatty matters, tannin, Prussian blue, and various coloring-matters. Treatment of logwood-dyed silk with hydrochloric acid (1.07 sp. gr.) at 50° to 60° C. will give a red color in the absence of Prussian blue, or leave a blue-black color if it is present. If Prussian blue is suspected, the silk should be treated with dilute caustic soda, the solution then acidulated with hydrochloric acid, and a few drops of a solution of ferric chloride then added; a blue precipitate will be produced if Prussian blue was originally present. The metallic oxides in the residue left on igniting a sample of the silk are best examined by fusing the ash with a mixture of nitre and sodium carbonate in a plati-

num or silver crucible. The fusion is treated with water, when the tin and chromium will go into solution as sodium stannate and chromate respectively, and the iron will remain insoluble as ferric oxide. After filtering and acidulating the filtrate with hydrochloric acid, the tin may be thrown down as sulphide by treatment with hydrogen sulphide, and after filtering off the latter the chromium is precipitated by addition of ammonia. For the detection of tannin a sample of the silk should be boiled in water, and a few drops of a solution of ferric acetate added, when a blue-black color is produced in the presence of tannin. The amount of tannin may be determined by dissolving it from the silk by means of an alkaline soap-bath, and finding the loss of weight on redrying. To determine the total proportion of weighting materials, a definite quantity of the silk dried at 110° C. should be boiled for an hour in a 2 per cent. solution of caustic soda, and then in dilute hydrochloric acid (250 cc. of commercial acid per litre). This treatment is repeated four times, washing the sample between each bath. The silk must be carefully handled, as it becomes quite brittle; after drying at 110° C. it is weighed; the loss in weight represents the total weighting materials. As a certain loss of silk occurs in this treatment, the amount of weighting material found is generally somewhat in excess of the truth. The chief source of error, however, is in the uncertainty of the allowance to be made for loss in the weight of the silk by boiling off. For boiled-off silk this figure (d) is taken at 25 per cent.; for souple silk at 8 per cent.; for écru at 0 per cent.; and for fancy silks at 10 per cent. Calling p the original weight of the sample, and D the weight after treatment, the percentage of weighting, W, may be calculated from the following formula:

$$W = \frac{(100-d) \times (p-D)}{D}.$$

In cases where the treated silk leaves a sensible amount (A) of ash on ignition, the following formula must be used:

$$W = \frac{(p-D+1.25A) \times (100-d)}{D-1.25A},$$

as the weight of the ash, if multiplied by the factor 1.25, will give approximately the amount of metallic hydroxides retained by the treated silk.

The foregoing method of Silbermann, however, is not sufficiently accurate for such a long and tedious process.

The method of analyzing weighted silk, recommended by Königs of the silk-conditioning establishment at Crefeld, is as follows: (1) Determine *moisture* by drying at 110° C.   (2) *Fatty matters* by extraction with ether.   (3) Boil out the *silk-glue* with water.   (4) Dissolve out Prussian blue with dilute caustic soda; reprecipitate by acidifying and adding ferric chloride, ignite precipitate with nitric acid, and weigh as ferric oxide; 1 part of $Fe_2O_3 = 1.5$ parts of Prussian blue.   (5) Estimate stannic oxide in ash of silk and calculate as catechu-tannate of tin; 1 part of $SnO_2 = 3.33$ parts of catechu-tannate.   (6) Estimate total ferric oxide in ash, subtract that existing as Prussian blue, and the amount naturally present in dyed silk (0.4 to 0.7 per cent.), and calculate the remainder to tannate of iron; 1 part of $Fe_2O_3 = 7.2$ parts of ferric tannate.

Perhaps the most accurate method of analyzing silk for total amount of weighting is to determine the amount of nitrogen present as silk by Kjeldahl's process.*   To do this it is first necessary to remove all gelatin, Prussian blue, or other nitrogenous matters.   This is effected by boiling a weighed quantity of the silk (about 2 gms.) with a 2 per cent. solution of sodium carbonate for thirty minutes.   The silk is then washed, and heated to 60° C. for thirty minutes in water containing 1 per cent. of hydrochloric acid, and afterwards well washed in hot water.   This treatment with alkali and acid should be repeated until the sample no longer has a blue color.   With souple or écru silks, ammonia or ammonium carbonate should be used instead of sodium carbonate, and the silk should be finally boiled for an hour and a half in a solution containing 25 gms. of soap per litre.   After this preparation the nitrogen determination is conducted as follows: The sample is placed in a round-bottomed flask of hard glass, and

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* Gnehm and Blenner, *Rev. Gen. Mat. Col.*, April, 1898.

treated with about 20 cc. of strong sulphuric acid, with the addition of a single drop of mercury. The flask is then heated, gently at first, and then to a vigorous boil; then 10 gms. of potassium sulphate are added and the boiling continued until the contents of the flask are clear and colorless. The contents are then washed into a distilling-flask and connected with a suitable condenser. By means of a tap-funnel, an excess of caustic soda solution is gradually added, together with a little sodium sulphide to decompose any nitrogen compounds of mercury that may have been formed. Some granulated zinc is placed in the flask to prevent bumping, and the distillate is collected in a measured quantity of standard acid, which takes up the ammonia that distils over. Excess of acid is determined by titration with standard alkali, using methyl orange as an indicator of neutrality. The above method is based on the fact that when silk (in common with the great majority of other nitrogenous organic substances) is heated with concentrated sulphuric acid, the whole of the nitrogen present is eventually converted into ammonia. Air-dried silk with 11 per cent. of hygroscopic moisture contains 17.6 per cent. of nitrogen, consequently the amount of true silk in a sample may be obtained by multiplying the percentage of nitrogen found by the factor 5.68. This method yields very accurate results if the determination of the nitrogen is carefully conducted.

A method for the determination of the weighting on silk which appears to be capable of yielding very good results is that suggested by Gnehm.* It depends on the fact that the silk fibre does not appear to be injured by treatment with either hydrofluosilicic acid or hydrofluoric acid. The method is carried out as follows: About 2 gms. of the silk to be tested are immersed, with frequent stirring, for one hour at the ordinary temperature of 100 cc. of a 5 per cent. solution of hydrofluosilicic acid. The treatment is then repeated with 100 cc. of fresh acid of the same strength. The silk is then washed several times with distilled water and dried. The loss in weight corresponds

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* *Zeits. Farben-u. Text. Chem.*, 1903, p. 209.

to the amount of inorganic weighting materials present. This method serves very well with silk weighted with stannic phosphate and silicate, but does not appear to be suitable for the estimation of weighting on black-dyed silks containing iron salts. It is said that oxalic acid may also be used (Müller, *Zeits. Farben- u. Text. Clem.*, 1903, 160) for the purpose of removing the inorganic weighting materials from silks, without injury to the silk fibre itself.

Taking all things into consideration, the author considers the following method to be the one best adapted for the commercial analysis of weighted silks: A portion (about 0.5 gm.) of the sample is placed in a weighing-bottle and dried in an air-bath at 105° C. to constant weight. It is then boiled in a 2 per cent. solution of hydrofluoric acid for five minutes, rinsed with water, and boiled for five minutes in a 2 per cent. solution of soda ash and washed. This alternate treatment with the hydrofluoric acid and soda ash solutions is repeated three times, after which the sample is finally rinsed, dried at 105° C., and reweighed. The loss in weight will represent weighting materials. The hydrofluoric acid may be prepared by diluting 11 cc. of commercial hydrofluoric acid to 400 cc. with water, and the soda ash solution by dissolving 2 gms. of sodium carbonate in 100 cc. of water. Three alternate treatments with these reagents will generally suffice to remove all weighting materials without appreciable injury to the silk fibre, though to be accurate the treatments should be repeated until no further loss in weight is observed.

The amount of weighting on silk is usually calculated on a basis of ounces per pound of raw silk, and expressed between a limiting variation of 2 ozs.; and it is further reckoned that 1 pound of raw silk is equivalent to 12.4 ozs. of pure silk fibre (boiled-off). A sample of silk described as 22/24, for example, would mean that 22 to 24 ozs. of such silk would be equivalent to 16 ozs. of raw silk. The amount of weighting as determined by the chemist should be calculated to percentage on the actual silk present, and then by use of the following table the corresponding ounces may be found.

Per Cent. Weighting.	Ounces.	Per Cent. Weighting.	Ounces.
0– 13	12/14	142–158	30/32
13– 29	14/16	158–174	32/34
29– 45	16/18	174–190	34/36
45– 61	18/20	190–206	36/38
61– 77	20/22	206–222	38/40
77– 93	22/24	222–238	40/42
93–109	24/26	238–254	42/44
109–125	26/28	254–270	44/46
125–142	28/30	270	46/48

For example: A sample of silk dried at 105° C. to constant weight proved to be 0.45 gm.   After treatments with hydrofluoric acid and so daash solutions as above described, dried again at 105° C., and reweighed, gave 0.31 gm. of silk as a residue.   Hence,

$$0.45 \text{ gram} = \text{weighted silk;}$$
$$0.31 \text{ `` } = \text{pure silk;}$$
$$\overline{}$$
$$0.14 \text{ `` } = \text{weighting,}$$

and
$$\frac{0.14 \times 100}{0.31} = 45 \text{ per cent. weighting,}$$

calculated from a basis of pure silk.   By reference to the foregoing table, it is seen that 45 per cent. weighting corresponds to 18/20 ozs. of silk.

As the silk fibre is very uniform in its structure and weight for any given length, an empirical method for determining the weighting on silk is as follows: The size of a single cocoon-thread averages $2\frac{1}{4}$ deniers (see p. 99); that is to say, 500 metres of such a filament will average 0.125 gm. in weight.   Hence, if yarn is being tested, a sample is observed under the microscope and the number of individual filaments present is counted; this number divided by two will give the number of cocoon-threads (as each cocoon-thread consists of two filaments).   A convenient length of the yarn is then taken and weighed, and from this the weight of 500 metres is calculated.   By multiplying the number of cocoon-threads observed by the factor 0.125, we obtain the weight of 500 metres of the yarn as pure silk.   The difference between

this weight and the former represents weighting, from which the percentage and ounces of weighting may be calculated as given in the foregoing paragraph.

For example: A portion of a single thread from a skein of silk yarn was carefully teased out so as to separate the individual filaments, and these were counted under a microscope. A series of three observations gave 19, 17, and 20 filaments, or a mean of 18.6. The weight of 50 metres of the silk was 0.146 gm. Hence

$$0.146 \times 10 = 1.460 \text{ grams} = \text{weight of 500 metres;}$$

$$0.125 \times \frac{18.6}{2} = 1.162 \quad \text{`` } = \text{weight of 500 metres of pure silk;}$$

$$0.298 \quad \text{`` } = \text{weighting,}$$

and
$$\frac{0.298 \times 100}{1.162} = 25.6 \text{ per cent. weighting,}$$

and this is equivalent to 14/16 oz. silk.

In case the sample to be examined is a woven fabric, it will be necessary to pick apart the warp- and weft-threads, and make separate counts of the filaments in each; then definite lengths of these threads may be measured off and weighed, and the calculation conducted as before. In making the count of the filaments in each thread of silk, the latter should be teased out as carefully as possible, in order to separate the individual filaments. This may readily be done by laying the thread on a glass microscope slide slightly moistened with water and separating the filaments with a needle. The number of filaments may then be counted through the microscope, using a low magnification. The count may also be made with the aid of a good magnifying-glass, but with more difficulty and less accuracy than when a microscope is employed. At least three separate counts of different threads should be made, and the average of these taken as the true number.

In case the length of the silk threads is measured in yards and not metres, a convenient amount to take for a test is 20 yds., then the following formula will hold.

Let A = weight of 500 metres of the weighted silk = weight of 20 yds. $\times 27.3$;

B = weight of 500 metres of pure silk = number of filaments $\times 0.062$,

and $\dfrac{A-B}{B} \times 100$ = per cent. of weighting.

The above formula is for weights expressed in grams; in case the weights employed are grains, we have

$$A = \text{weight of 20 yds.} \times 27.3;$$

$$B = \text{number of filaments} \times 0.956.$$

and $\dfrac{A-B}{B} \times 100$ = per cent. of weighting.

These formulas may be simplified as follows:

(a) In case gram weights are used

$$w = \text{weight of 20 yds. of the silk;}$$
$$n = \text{number of filaments;}$$

$$\frac{438w - n}{n} \times 100 = \text{per cent. of weighting.}$$

(b) In case grain weights are used

$$\frac{28.4w - n}{n} \times 100 = \text{per cent. of weighting.}$$

The accuracy of this method for determining the degree of weighting of silk is based on the fact that the fibre is very uniform in size, and hence the weight of a given length of fibre may be assumed as being constant. This, however, is only true within certain limits and with respect to certain grades of silk. By reference to the table on page 99, it will be seen that the variation in size (or weight for a given length) of silks from different countries is quite considerable; hence, to apply the foregoing method

properly, the origin of the silk should be known. In the case of tussah or other varieties of wild silk the variation in size is much more considerable; hence the limit of error in this method is much larger and the results are not sufficiently accurate to be at all reliable.

6. Oil and Grease in Yarns and Fabrics.—An estimation of the amount of oil and grease is frequently required for woolen or worsted cloth, yarn, tops, roving, etc. A method leading to approximate results, which are generally sufficiently accurate for commercial purposes, is to weigh off a sample of the material to be tested and scour it for thirty minutes in a solution containing 5 gms. of good quality soap per litre at a temperature of 140° F. It is then rinsed well in warm water a couple of times to remove all of the soapy liquor, and then dried. Before reweighing it should be left in the air for about an hour, so as to come to the same hygroscopic condition as when first weighed. The loss in weight will represent the oil, grease, and any dirt in the fibre, and may be called the " scouring loss."

A more accurate method to determine the oil and grease is to weigh off about 5 gms. of the material and agitate in a flask with about 100 cc. of petroleum ether for twenty minutes. This will dissolve all oily matters present, and the liquid may be poured into a weighed evaporating-dish. The residual fibre is washed with about 100 cc. more of petroleum ether; the latter is added to the first extraction and the whole evaporated to dryness on a water-bath, and the weight of the residue of oil in the evaporating dish is determined, cr the extracted fibre may be removed from the flask, dried, exposed to the air for an hour and reweighed, and the loss in weight will represent grease and oil.

In the two preceding methods where the air-dry weights are used, care should be especially taken to weigh the material before and after under the same hygroscopic conditions, otherwise considerable variations in results may be obtained by reason of the fibre absorbing a greater or less quantity of moisture; where accurate results are demanded, it will be necessary to make three weighings, as follows: (*a*) the weight of the air-dry

material, (*b*) the weight of the material after drying at 105° C. for one hour, (*c*) the weight of the extracted material after drying for one hour at 105° C. In this manner the somewhat uncertain factor of moisture is eliminated. The percentage of grease in the material, however, should be calculated on the weight of the air-dry fibre. For example: a sample of woolen yarn weighing 5.026 gms. was dried at 105° C. for one hour and when weighed again gave 4.516 gms.; after extraction with petroleum ether and drying again as before, it weighed 4.271 gms. The amount of grease in this case was therefore $4.516 - 4.271 = 0.245$ gms. or $(0.245 \times 100) \div 5.026 = 4.67$ per cent.

A still better and more accurate method for the determination of grease is to treat a weighed sample of the material in a Soxhlet extraction apparatus with petroleum ether, evaporating off the solvent and weighing the residue of grease. The analysis is determined as follows: The small flask of the apparatus is weighed and then about half-filled with petroleum ether (about 50 to 75 cc.); about 2 gms. of the material to be extracted is accurately weighed and placed in the extraction tube or capsule, after which the several parts of the apparatus are connected and the flask is heated on a water-bath until all the oil or grease has been extracted and dissolved by the petroleum ether. According to the form of apparatus employed, this may require from twenty minutes to one hour. The flask is then removed and the solvent is distilled off. The residual grease in the flask is then dried for one-half hour on the water-bath and after cooling weighed. The increase in the weight of the flask represents the amount of grease.

7. **Estimation of Finishing Materials on Fabrics.**—Cotton fabrics are quite generally sized or otherwise finished for the purpose of giving the cloth a better handle or a greater weight. For this purpose a wide variety of substances may be used, but starch is nearly always the basis of the sizing. Soaps, fats, gelatin, vegetable mucilages, resin, and china clay are also of common occurrence. In some cases hygroscopic salts, such as calcium chloride, magnesium chloride, or zinc chloride are used to obtain certain effects or to increase the weight of the

goods.* Woolen goods are sometimes sized or weighted in a similar manner, both for purposes of producing certain finishes and of fraudulently increasing the weight of the fabric.

According to Hoyer,† cotton cloth in the gray or unbleached state should consist approximately of 83 per cent. fibre, 7 per cent. moisture, 8.5 per cent. of starch and fatty matters (used for softening the yarn and sizing the warp), and 1.5 per cent. of ash. After boiling-out and bleaching, however, only 78 per cent. of fibre is left, so that by the addition of dressing the finished cloth consists of 78 per cent. fibre, 7 per cent. moisture, 7 per cent. starch, and 7.5 per cent. mineral matter. If the amount of fibre falls below 78 per cent. in bleached calico or much below 83 per cent. in gray calico, it may be supposed that the cloth is loaded.

Linen fabrics should contain but a small amount of finishing or dressing materials. Usually a small quantity of starch is required for the purpose of sizing the warps, but no mineral matter should be present beyond that to be found in the natural fibre itself. Linen cloth should not lose more than 5 per cent. when boiled in water.

8. **Testing the Water-proof Quality of Fabrics.**—A large variety of fabrics are now finished so as to be more or less water-proof or, more strictly speaking, water-resistant. Fabrics of cotton, wool, silk, or of mixed fibres may be given this property. It is not the purpose at this point to enter into the methods by

* Thompson, *Sizing of Cotton Goods*, p. 150, gives the following typical analyses of cotton fabrics:

	I.	II.	III.	IV.	V.	VI.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Material:						
Fibre............	47.29	53.02	60.75	70.84	80.51	81.78
Normal moisture....	4.11	4.61	5.28	6.16	7.02	7.11
Weight of cloth......	51.40	57.63	66.03	77.00	87.53	88.89
Dressing:						
Water.............	6.01	5.02	4.65	3.07	2.01	2.89
Dressing and fat.....	12.77	13.36	13.33	12.43	8.30	3.33
Mineral matter......	29.82	23.99	15.99	7.50	2.16	4.89
Weight of Dressing..	48.60	42.37	33.97	23.00	12.47	11.11

† Dammer's *Lexikon der Verfälschungen.*

which water-proofing is carried out, but simply to give the methods employed for testing such fabrics.

In Germany the following test is prescribed for sail-cloth: A sample of the cloth 10 inches square is folded like a filter-paper and placed in a suitable glass funnel where 300 cc. of water are poured upon it and it is left for twenty-four hours. At the end of this time only a few equally distributed drops of water should be discovered on the under surface of the cloth, and the fabric should not be wet through.

Gawalowski describes an apparatus for determining the water-proof qualities of a fabric as follows: The sample of the cloth is attached to the open end of a graduated tube (a burette will serve the purpose, using the large opening for the cloth), which is then filled with a column of water 12 inches in height. At the end of twenty-four hours an observation is made as to how much water has passed through the cloth.
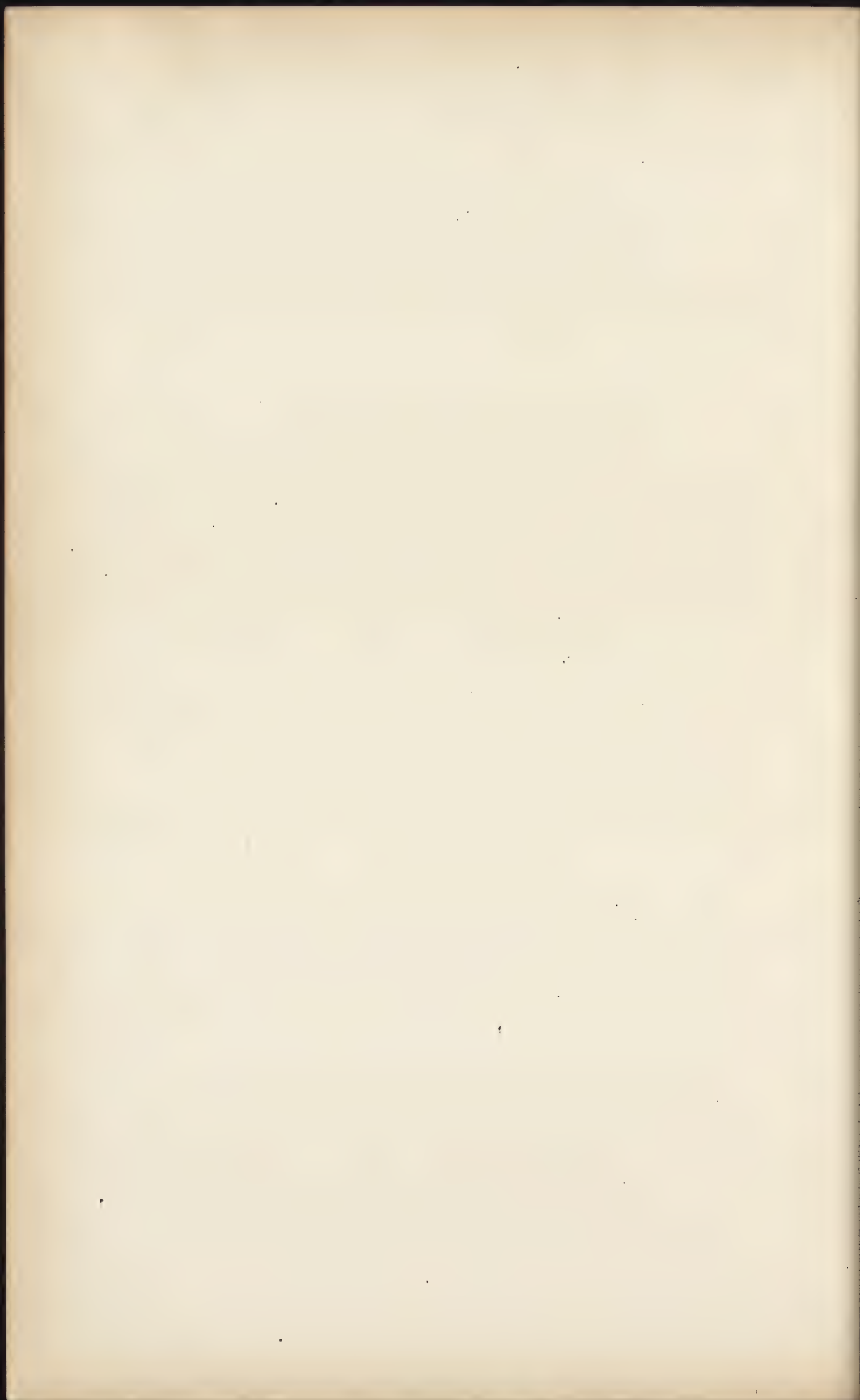
APPENDIX I.

MICROSCOPIC ANALYSIS OF FABRICS.

HÖHNEL describes the following method employed for a micro-
scopic examination of textile fabrics, where the object is to deter-
mine not only qualitatively the character of fibres composing
them, but also their quantitative amounts. With regard to the
preliminary qualitative examination, there are generally only a few
fibres to be taken into consideration, as there seldom occur in the
same fabric more than one to four different kinds of fibres. As
a rule, the only fibres which will be found are cotton, linen, hemp,
jute, ramie, sheep's wool, goat-hair, cow-hair, angora, alpaca,
cashmere, llama, silk, and tussah silk. In woolen material there
are also cosmos and shoddy to be considered.

To undertake the examination, cut off a sample of the mate-
rial 2 to 3 sq. cm. in size, and separate this into its warp- and fill-
ing-threads. The sample must be of sufficient size to include
all of the different kinds of yarns employed in the weave. Con-
sequently, in the case of large patterns, it has to be rather large.
The warp- and filling-threads are laid next to each other, and one
of each kind is selected to serve for further examination. In the
simplest case there is only one kind of warp-thread and one kind
of filling present, which necessitates, therefore, the examination
of only two different yarns. In complicated cases there may be
as many as ten, or even more, different yarns to analyze. In
woolen fabrics there will frequently be found yarns which are
composed of two or three different threads twisted together;
these must be untwisted and each separate yarn examined by
itself. In order to attain satisfactory results, the operator must

be sufficiently skilled in the microscopy of the fibres to be able to recognize with certainty, under a low magnification, the different fibres liable to be found. By a low magnification is meant one of fifty to sixty times. A much higher power cannot be used in the examination of fabrics, for hundreds or even thousands of fibres have to be taken into consideration. From ten to twenty fibres, or perhaps more, should be obtained in the field at the same time, and it is necessary to be able to promptly recognize the different ones. With a higher magnification, it is true, the single fibres can be better recognized, but the general view is then lost, and there is danger in overlooking whole bundles of fibres. If the observer finds a fibre which cannot be recognized with sufficient accuracy by means of the low power, it is a simple matter to so change the objective as to increase the magnification to allow of the necessary observations to be made, and then to proceed again with the examination under the lower power.

Dark-colored material often consists for the most part of threads which, on microscopic examination, appear quite opaque, hence dark and structureless. Therefore it will frequently be necessary to remove the dyestuff, at least in part, which is usually done by boiling in acetic acid, hydrochloric acid, dilute caustic alkali, potassium carbonate, etc., until sufficiently light in appearance.

In the case of very accurate examinations, each different kind of thread must be examined separately, and the number of fibres composing it, together with their kind and color, must be noted. In order to show the detail and scope of such an examination, the following example is given: On unravelling a sample four different warp-threads and one filling-thread were obtained. One of the warp-threads was composed of two yarns twisted together one of which was black (K_1a) and the other white (K_1b) Two warp-threads were dark blue $(K_2$ and $K_3)$ and the fourth was a gray mix (K_4); the filling-thread (E) was blue. On examination the following results were obtained:

K_1a showed 85 shoddy fibres (mostly black, some yellow and red and even isolated green fibres of wool, and 13 cotton fibres)

K_1b showed 31 pure white wool fibres.

K_2 and K_3, respectively, showed 46 and 53 pure blue wool fibres.

K_4 showed 60 shoddy fibres, of which 32 were mostly gray or black wool fibres, and 28 were gray cotton fibres.

E showed 60 blue wool fibres.

Therefore in this sample, including 4 wa p- and 4 filling-threads, there would be $85+31+46+53+60=275$ single-warp fibres; and $60\times4=240$ filling fibres; or 515 single fibres altogether. Of these 41 were cotton, which were found in the shoddy, the latter comprising 145 fibres in all. Hence in a sample of this piece of goods containing equal lengths of warp and weft, there are 41 cotton fibres, 104 shoddy wool fibres, and 370 pure wool fibres, from which the respective percentages would be:

	Per Cent.
Cotton...	8.0
Shoddy wool.	20.2
Pure wool..	71.8
	100.0

This, of course, only gives the relative percentages of the number of fibres; if it is desired to reach an approximate idea of the proportions by weight, then micrometric measurements must be made of the wool and cotton fibres occurring in the sample. In consideration of the fact that wool possesses about twice the cross-section of cotton, it becomes a rather easy matter to calculate the ratio between the two, by means of which the percentage by weight can be readily obtained, provided that the specific gravity of wool is taken to be about the same as that of cotton, which is approximately true.

APPENDIX II.

MACHINE FOR DETERMINING STRENGTH OF FIBRES.

THERE have been a number of machines devised for the purpose of determining the tensile strength and elasticity of fabrics and yarns, and a few instruments have also been adapted for the testing of single fibres. As the individual fibre, however, is a very slender and delicate object, especially in the case of certain vegetable fibres, the determination of its physical factors is an operation which requires a delicately adjusted apparatus. In machines which require the taking on or off of weights, the jar is usually sufficient to break the fibre before its true breaking strain is reached. The same criticism is also true for machines employing water as a weight. A machine devised for the use of the Philadelphia Textile School has proved very satisfactory for determining the tensile strength and elasticity of almost any fibre, from very fine and delicate filaments to coarse and strong hairs. A diagrammatic drawing of this machine is given in Fig. 127. The fibre to be tested is clamped between the jaws at (J), the pointer attached to the end of the beam above the upper jaw being brought to the zero-mark on the scale (S), while the lower jaw is raised or lowered in its stand until the desired distance between the jaws is obtained. To obtain comparable results this distance should always be the same; and 10 cm., in the case of long fibres, or 2 cm. for short fibres, have proved to be good lengths of fibre to test. The sliding-bar (R) is moved forward by turning the rod (T), which moves the rack and pinion at (P), until the graduation on the wheel (G) is at zero to the indicator. Under these conditions there is no strain on the fibre. A stretch-

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ing-force is then placed on the fibre by moving the bar (*R*) back-ward by turning the rod (*T*); the motion of this bar is made uniform and gradual until the fibre finally breaks under the strain thus placed upon it. The graduation on the wheel (*G*) will then indicate in decigrams the breaking strain of the fibre being tested. The elasticity is obtained by watching carefully the pointer moving up the scale of millimetres at (*S*) until the rupture
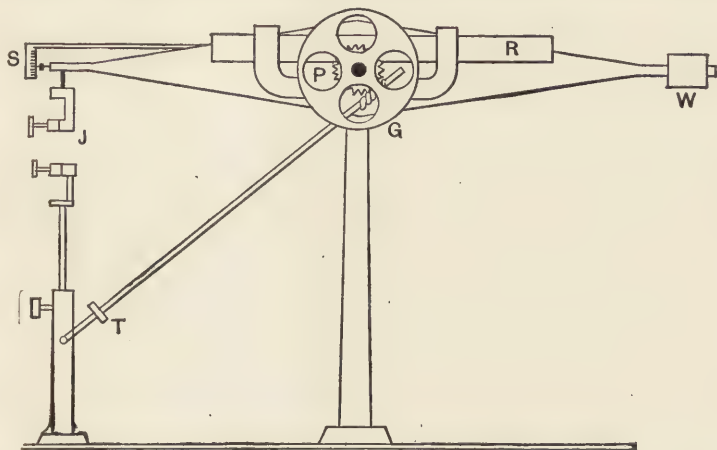
FIG. 127.—Fibre-testing Machine.

J, jaws with screw-clamps for holding the fibre; the lower jaw may be raised or lowered; *R*, sliding-rod working on a rack and pinion; this takes the place of weights; *G*, wheel graduated on its face in decigrams, moving on the same axis as the pinion for sliding the weight; *T*, thumb-screw for turning the small shaft working the pinion at *P*; *W*, counterbalancing weight for regulating the zero-point of the machine; *S*, scale for reading the stretch of the fibre. (Drawing by author.)

of the fibre takes place; the distance this pointer moves represents the actual stretch of the fibre, and if the length of fibre taken between the jaws is 10 cm., this figure will represent directly the percentage of elasticity. If the length of fibre taken is only 2 cm., to obtain the percentage of elasticity it is nece sary to multiply the amount of stretch in millimeters by five; and for other lengths of fibre similar proportions will hold. The weight (*W*) at the rear end of the beam can be moved backward or forward, and is for the purpose of adjusting the balance so that there is no strain at (*J*) when the indicator on (*G*) marks zero. The wheel (*G*) is graduated in decigrams, and this marks the sensibility of

the machine; the total graduations on (G) running from zero to 400. When fibres are tested having a greater tensile strength than 400 decigrams a fixed additional weight of 10, 25, 50, etc., grams may be hung from (W), and this must be added to the reading on the wheel when the fibre breaks. If the elasticity of the fibre is so great as to carry the pointer beyond the limits of the scale at (S), a shorter length of fibre must be tested. A fair average of breaking strain and elasticity may be obtained for any quality of fibre by testing about 10 separate fibres and taking a mean of the total tests. If the quality of the fibres, however, in a sample does not run very uniform, it is best to increase the number of tests to 25 or even 50 in order that a satisfactory average may be obtained.

This machine is capable of being used with all classes of fibres, and its results are very satisfactory, as has been proved by several years' use at the Philadelphia Textile School.

APPENDIX III.

COMMERCIAL VARIETIES OF AMERICAN COTTON.

THE following material relative to the different varieties of American cotton has been based on the Report of the U. S. Dept. of Agriculture on this subject. The following varieties and their characteristics have been recorded:

Acme (Allen Acme).—From Mississippi; evidently a mixture of some long-stapled variety and sea-island; it is not a hybrid, and does not seem to have any special value.

Allen (Allen Silk, Allen Long Staple, Talbot).—From Mississippi; plant vigorous, pyramidal, long-limbed; bolls large, opening very widely, and sometimes allowing the seed cotton to drop; maturing late; lint 28 to 30 per cent., staple 30 to 35 mm., fine and silky.

Alred.—History unknown; evidently of the Rio Grande type; reported only once from Mississippi.

Alvarado.—History unknown; evidently Peterkin; reported once from Georgia.

Audrey Peterkin. (See Peterkin.)

Bahama. (See Texas Storm Proof.)

Bailey.—Originated in North Carolina; plant of medium size, early and prolific for a long-stapled variety; lint 28 to 30 per cent., staple 28 to 32 mm. An excellent long-stapled variety for uplands.

Banana (Cluster, Hogan, Prout).—This variety is now obsolete.

Bancroft Herlong. (See Herlong.)

Bancroft Prolific Herlong. (See Herlong.)

Bancroft Prolific Long Staple.—Origin unknown; yield much below the average.

Barnes.—One of the older varieties; plant vigorous, short-limbed and inclining to cluster, similar to Herlong in habit; bolls above medium size, maturing late.

Barnett.—From Alabama; origin unknown; plant tall and slender, limbs short; bolls medium size, rounded, not maturing early; lint 30 to 32 per cent., staple 23 to 25 mm.

Bates Big Boll.—Originated in South Carolina, developed from the Rio Grande type; plant vigorous and very symmetrical; well-branched; bolls rather large, not maturing early; lint 33 to 35 per cent., staple 24 to 27 mm.

Bates Favorite.—Similar in origin to above; plant very vigorous, branching widely; bolls medium size, maturing late; lint 30 to 32 per cent., staple 24 to 27 mm.

Belle Creole.—The immediate successor to the Jethrox; stalk large, tall, and productive; boll large and long; seed commonly flat on one side with an indentation; lint abundant, long, firm, silky, soft, lustrous; a very oily cotton.

Ben Smith (Ben Smith Choice, Bush, Smith Standard).—From Louisiana; plant strong, widely pyramidal; bolls medium size, usually two at each joint; not maturing early; lint 32 to 33 per cent., staple 23 to 26 mm. Probably descended from Purple Stalk or Red Leaf.

Big Boll.—From California; history unknown; supposed to be of Texas origin; plant medium size, limbs rather long; bolls large, oblong, maturing late; lint 34 to 35 per cent., staple 25 to 28 mm.

Black Seed.—This name is usually applied both to sea-island varieties and to upland varieties having a smooth seed.

Bob, Bob Silk, Bob White. (See Ozier.)

Bolivar County.—A Louisiana variety of the Storm Proof type; maturing early, with 29 to 30 per cent. of lint.

Borden Prolific.—Occurs in South Carolina, but no description available.

Boyd Prolific.—One of the oldest improved varieties; plant upright, slender, moderately vigorous, short-limbed; bolls small,

round, in clusters, medium in time of ripening; lint 30 to 32 per cent., staple 20 to 24 mm.

Brady.—Occurs in North Carolina, but no description available.

Bragg Long Staple.—This appears to be a true hybrid between *G. herbaceum* and *G. barbadense;* plant very vigorous, well-branched; bolls oblong, large, maturing late; lint 30 per cent., staple very variable, mostly 35 mm., some 75 mm.

Brannon (Little Brannon).—One of the older varieties, originating in Texas; plant medium growth, well-branched; limbs short-jointed; bolls small, medium in time of ripening; lint 32 to 35 per cent., staple 18 to 22 mm. Belongs to the Rio Grande type.

Brazier Peterkin. (See Peterkin.)

Brooks Improved. — A Louisiana variety; maturing early; lint 31 to 32 per cent., staple short.

Brown.—From Mississippi; maturing early; staple short.

Bush. (See Ben Smith.)

Carolina Pride. (See Early Carolina.)

Catacaos. (See Peruvian.)

Catawba.—From South Carolina; maturing late; lint 35 to 36 per cent., staple 23 to 25 mm.

Chambers.—From South Carolina; belongs to Herlong type; lint 32 per cent., staple 22 to 25 mm.

Champion Cluster.—Plant very vigorous with long limbs; bolls large, oblong, maturing late; lint 30 to 31 per cent., staple 25 to 28 mm.

Cherry Cluster (Cherry).—From South Carolina; plant of medium growth, cone-shaped; limbs of medium length; bolls small, round, clustered, maturing early; lint 30 to 32 per cent., staple 18 to 22 mm.

Cherry Long Staple Prolific.—Closely allied to the above.

Cluster. (See Banana.)

Cobweb (Spider Web).—From Mississippi; claimed to be a hybrid between Peeler and an Egyptian variety; plant very vigorous, long-limbed; bolls large, somewhat pointed, maturing

late; lint 28 to 29 per cent., staple 35 to 40 mm., very fine and silky.

Cochran (Cochran Extra Prolific, Cochran Short-limbed Prolific).—From Georgia; plant moderate grower, slender, short-limbed; bolls medium size, round; lint 32 to 33 per cent., staple 35 to 40 mm.

Colthorp Eureka.   (See Eureka.)

Colthorp Pride.—From Louisiana; plant vigorous, upright, pyramidal; bolls oval, large, maturing late; lint 28 to 30 per cent., staple 28 to 32 mm.; seed small and many of them black.

Cook.—From Mississippi; plant very vigorous and prolific; limbs irregular, not long; bolls large and long, maturing late; int 26 to 28 per cent., staple 35 to 40 mm.   One of the best varieties for low rich ground.

Cox Royal Arch Silk.—From Georgia, similar to Ozier Silk.

Crawford Peerless (Crawford Premium).—From South Carolina; practically identical with Peerless, except that the bolls are usually clustered.

Crossland.   (See Peterkin.)

Dalkeith Eureka.   (See Eureka.)

Dean.—Local variety of South Carolina.

Dearing (Dearing Prolific, Dearing Small Seed).—Very similar to Herlong; it is claimed that 45 per cent. of lint has been obtained from this.

Diamond.—Developed from the Rio Grande type.

Dickson (Dixon, Dickson Cluster, Dickson Improved, Simpson).—Plant vigorous, well branched, pyramidal; limbs short; bolls medium to large; round, clustered, maturing rather early; lint 31 to 32 per cent., staple 23 to 26 mm.   One of the most popular cluster varieties.

Drake Cluster.—Developed from Peerless, which it resembles in every way, except that it matures somewhat earlier and the bolls are more clustered; lint 31 to 32 per cent., staple 22 to 25 mm.   One of the most popular varieties for uplands.

Drought Proof.   (See Texas Storm Proof.)

Duncan (Duncan Mammoth).—From Georgia; a late ripening, large boll, long-staple variety, similar to Mammoth Prolific.

Early Carolina (Extra Early Carolina, Carolina Pride, South Carolina Pride).—An early ripening variety developed from the Dickson and very similar to that form.

East (East Improved Georgia).—A long-staple variety similar to Allen, but maturing earlier and having a little shorter staple; lint 31 to 32 per cent.

Ellsworth.—From North Carolina; plant usually with long spreading limbs; bolls large, oblong, maturing late; lint 30 to 33 per cent., staple 21 to 24 mm.

Ethridge.—From Louisiana; plant of fair size; limbs long and spreading; maturing late; staple fine and silky, 28 to 30 mm.; seed black.

Eureka (Colthorp Eureka, Dalkeith Eureka, Humphrey Eureka).—Plant large and prolific; limbs of medium length; bolls rather large, oblong, not maturing early, holding the seed well in wet weather; lint 28 to 30 per cent., staple 35 to 40 mm., very fine, strong, and silky; seed quite small and sometimes black. One of the most popular long-staple varieties.

Excelsier.—Developed from New Era; similar to Peterkin, though with bolls a trifle larger; lint 33 to 35 per cent., staple 26 to 30 mm.

Farrar Forked Leaf. (See Okra.)

Farrell Prolific.—Plant medium size, with very long and straggling limbs; very prolific; bolls large, oblong; lint 28 to 30 per cent., staple 30 to 35 mm., similar to Mammoth Prolific.

Garber.—Local Alabama variety of the Rio Grande type.

Georgia Prolific (Georgia Upland).—These are names applied to a number of upland short-staple varieties of the Peterkin and Herlong types.

Gold Dust. (See King.)

Grayson Early Prolific.—Plant medium in size; limbs short, not spreading widely; very prolific; bolls medium in size, somewhat clustered, ripening early; lint 34 to 36 per cent., staple 22 to 25 mm.

Griffin.—Plant vigorous with pale-green leaf, prolific; bolls large, medium in time of maturing; lint 28 to 29 per cent., stalpe very fine and silky, occasionally fibres 70 to 75 mm. The longest nd finest staple found.

Gunn.—A Mississippi local variety of the Rio Grande type.

Hawkins (Hawkins Extra Prolific).—Plant very vigorous, well-branched, pyramidal; prolific; bolls medium in size, roundish, early or medium in time of maturing; lint 32 to 34 per cent., staple 18 to 22 mm.

Hays China.—Very similar to the Allen.

Herlong (Bancroft Herlong, Jones Herlong, etc.)—Plant medium in size, well-branched, pyramidal, very prolific; bolls medium in size, round, maturing rather late; lint 30 to 32 per cent., staple 20 to 25 mm. A semi-cluster variety very popular in Georgia and Alabama.

Hightower.—An Alabama local variety, strong growing, bolls very large, and staple of medium length.

Hilliard.—Of the Rio Grande type, and not differing essentially from Peterkin.

Hogan. (See Banana.)

Hollingshead.—One of the oldest varieties on record. Supposed to be of Mexican origin, but is now apparently obsolete.

Howell.—From Louisiana; very similar to Peterkin, but maturing earlier.

Humphrey Eureka. (See Eureka.)

Hunnicutt (Hunnicutt Choice).—Plant large and well-branched, branches spreading, prolific; bolls of medium size, roundish, maturing early; lint 30 to 32 per cent., staple 22 to 25 mm.

Improved Long Staple. (See Jones Long Staple.)

Improved Prolific.—A local variety from North Carolina, very similar to Herlong.

J. C. Cook.—Descendant of old Purple Stalk type, apparently identical with Ben Smith.

Jenkins (Jenkins Poor Man's Friend).—Plant strong, pyramidal, prolific; bolls medium in size, oval, maturing early; lint 34 to 36 per cent., staple 22 to 25 mm. One of the best of the Rio Grande type.

Jethro (McBride Silk).—This is the parent stock of Jones Long Staple, Six Oaks, and a number of others, but does not now seem to be in cultivation.

Jones Herlong. (See Herlong.)

Jones Improved (Jones Improved Prolific).—Plant medium size, limbs short and spreading, not very prolific; bolls large, roundish, maturing late; lint 30 to 32 per cent., staple 20 to 24 mm.

Jones Long Staple (Improved Long Staple, Richardson Improved).—Plant large, limbs long and spreading, prolific; bolls large, oval, pointed, maturing medium or late; lint 29 to 30 per cent., staple 30 to 34 mm. A descendant of the Jethro, and one of the most popular of the long-staple varieties for the middle and southern parts of the cotton belt.

Jones No. 1.—A local Alabama variety of the Rio Grande type; lint 33 to 34 per cent., staple 18 to 22 mm.

Jowers (Jowers Improved).—Similar to the Peterkin and probably the same.

Jumbo.—Similar to the Hawkins, but more prolific.

Kelly. (See Marston.)

Kieth.—From Alabama; plant tall, pyamidal; limbs short-jointed, prolific; bolls medium size, rounded, not clustered, maturing early; lint 30 to 32 per cent., staple 24 to 27 mm.

King (Gold Dust, King Improved, Tennessee Gold Dust).— Plant medium size, pyramidal, well-branched, very prolific; bolls small, rounded, maturing early; lint 32 to 34 per cent., staple 25 to 28 mm. One of the most desirable varieties.

Lewis Prolific. (See Sugar Loaf.)

Little Brannon. (See Brannon.)

Louisiana.—This name is applied to a number of upland short-staple varieties.

Magruder Marvel.—Plant pyamidal, limbs abundant and short-jointed; bolls small, round, and somewhat clustered, maturing early; lint 31 to 33 per cent., staple 25 to 30 mm.

Magruder XL.—Early and prolific; lint 32 to 34 per cent., staple 25 to 30 mm.

Mallius Prolific.—A local Louisiana variety.

Mammoth Cluster.—From Georgia and one of the old varieties, similar to Champion Cluster.

Mammoth Prolific.—Plant very strong, well-branched, not very prolific; bolls very large, oblong, maturing very late; lint

30 to 32 per cent., staple 26 to 31 mm. Very similar to Duncan.

Marston (Kelly)—Plant medium growth, limbs short, prolific; bolls fair size, round, maturing late; lint 30 to 31 per cent., staple 26 to 30 mm.

Martin Prolific.—From Louisiana; apparently the same as above.

Mastodon.—From Mississippi; seems to have disappeared.

Matthews.—Plant very vigorous, pyramidal, with limbs from near the ground; limbs short-jointed, very prolific; bolls large, ovate, pointed, maturing early; lint 29 to 30 per cent., staple 35 to 40 mm. Gives a remarkably good yield for a long-staple variety.

Mattis.—Plant vigorous, limbs long, short-jointed, prolific; bolls clustered, medium in size, maturing rather late; lint 30 to 32 per cent., staple 25 to 30 mm.

Maxey (S. B. Maxey, Meyers, Meyers Texas).—Plant medium size, well-branched, prolific; bolls large, roundish; lint 31 to 32 per cent., staple 30 to 35 mm.

McAllister Peerless. (See Peerless.)

McBride. (See Jethro.)

McCall.—Once popular in South Carolina, but now obsolete; similar to Truitt.

McIver.—A local variety of South Carolina, similar to above.

Mexican.—One of the oldest known varieties; the larger proportion of our short and medium stapled varieties have been developed from this.

Mexican Burr.—A variety of the above, with bolls in clusters and the original source of many of the present cluster varieties.

Meyers. (See Maxey.)

Minter (Minter P. olific).—Plants large, branched low and widely, prolific; bolls medium in size, round or oval, maturing late; lint 30 to 32 per cent., staple 22 to 25 mm., similar to Herlong.

Moina.—Remarkable for the number of its limbs; fibre long and fine, said to surpass Peeler; bolls abundant, but as it is difficult to pick and gin is not now cultivated much.

Money Bush.—One of the old varieties in Mississippi; probably same as Banana.

Moon.—Plant strong, limbs long and spreading; bolls large, oval, medium maturing; lint 31 to 33 per cent., staple 30 to 35 mm., strong and silky.

Multibolus.—Sometimes called Sugar Loaf; a cluster variety which has now disappeared.

Multiflora.—An early Alabama variety similar to the Banana, but with large clusters of bolls and lighter colored seeds.

Oats.—Plant vigorous, sugar-loaf in shape, very prolific, maturing early; lint 32 to 34 per cent., staple 20 to 25 mm.

Okra (Okra Leaf, Farrar Forked Leaf).—One of the older varieties; plant of medium growth, limbs short and upright; leaves with very narrow lobes; bolls clustered, round, small, maturing early; lint 32 to 34 per cent., staple 24 to 26 mm.

Ozier (Ozier Silk, Bob, Bob Silk, Bob White, Tennessee Silk).—Plants medium size, pyramidal, limbs rather short, moderately prolific; bolls medium in size, oval, ripening early; lint 30 to 32 per cent., staple 25 to 28 mm.

Pearce.—An early maturing variety, with 32 to 33 per cent. of lint.

Peeler.—Plant very large and vigorous, branching widely; bolls large, maturing late; lint 30 to 32 per cent., staple very strong and silky, 25 to 28 mm.   One of the most widely cultivated varieties.

Peerless (Crawford Premium, Crawford Peerless, McAllister Peerless, Sutton Peerless, The Premium).—Plant medium, well-branched, pyramidal; bolls small or medium in size, round, sometimes clustered, maturing early; lint 32 to 33 per cent., staple 23 to 27 mm.   One of the best of the upland varieties.

Peruvian (Catacaos).—A South American variety of *G. arboreum*, which never matures its fruit in the United States.

Peterkin (Audrey Peterkin, Brazier Peterkin, Crossland, Texas Wood, Wise).—Originally with smooth black seeds, and producing nearly 50 per cent. of lint. Plant of medium size, well branched, limbs short-jointed; bolls medium in size, oval, not clustered, not maturing very early; lint 34 to 36 per cent.,

staple 22 to 25 mm. One of the largest producers of lint and one of the best of the Rio Grande type.

Peterkin Limb Cluster (Peterkin New Cluster).—Similar to the above, except that the bolls are somewhat clustered.

Petit Gulf.—One of the oldest varieties; plant large, long-limbed and long jointed, not very prolific; bolls medium in size, ovate, not maturing early; lint 30 to 32 per cent., staple 22 to 25 mm.

Pittman (Pittman Extra Prolific, Pittman Improved).—A cluster variety from Louisiana, similar to the Dickson; early maturing and short limbed.

Pitt Prolific.—Once grown in Mississippi, but no longer in cultivation.

Pollock.—A cluster variety, maturing somewhat later than the Peerless; staple 35 to 40 mm.

Poor Man's Relief.—From California, similar to Peterkin.

Prolific. (See Sugar Loaf.)

Prout. (See Banana.)

Queen (Southern Queen).—A local variety from Arkansas, similar to Peterkin.

Rameses.—Old variety, similar to Peerless.

Richardson Improved. (See Jones Long Staple.)

Rio Grande.—Original form of many of the upland short-staple varieties; lint 34 to 36 per cent., staple 18 to 22 mm.

Rod Smith 25 Cent.—Once grown in Mississippi, but not now in cultivation.

Roe Early.—A local variety from Louisiana; maturing early; lint 28 to 30 per cent., staple 25 to 30 mm.

S. B. Maxey. (See Maxey.)

Sea-island.—Native of West Indies and Central America, one of the first varieties cultivated in the United States; staple long and fine and commands the highest price, but is not profitable to grow more than 50 miles from the Atlantic coast.

Shine Early.—An early maturing variety of the Rio Grande type, similar to Peterkin.

Silk. (See Jethro.)

Simpson. (See Dickson.)

Six Oaks.—Similar to Jones Long Staple, but plant less vigorous; bolls not so large, and seeds are smooth and black; lint 28 to 30 per cent., staple 35 to 40 mm.

Smith Standard. (See Ben Smith.)

South Carolina Pride. (See Early Carolina.)

Southern Hope.—Plant pyramidal, limbs strong and straight, prolific; bolls large, pointed, maturing rather late; lint 30 to 32 per cent., staple 28 to 32 mm. One of the best types for the southern belt, but maturing too late for the northern latitudes.

Spider Web. (See Cobweb.)

Storm Proof. (See Texas Storm Proof.)

Sugar Loaf (Lewis Prolific, Prolific, Vick 100 Seed).—Originated from Mexican seed; a cluster variety which is now obsolete.

Sutton Peerless. (See Peerless.)

Talbot. (See Allen.)

Tarver.—Early Alabama variety, probably same as Sugar Loaf.

Taylor.—This name is applied to two distinct varieties, the one in Alabama having a small boll and short staple, the other in South Carolina having a large boll and long staple.

Tennessee Gold Dust. (See King.)

Tennessee Silk. (See Ozier.)

Texas Storm Proof (Bahama, Drought Proof, Storm Proof).—Plant tall with slender and often drooping limbs, not very prolific; bolls large, pointed, maturing late; lint 33 to 35 per cent., staple 23 to 26 mm. Called " storm proof " because the matured seed cotton does not fall from the bolls as readily as with most varieties.

Texas Wood.—Probably identical with Peterkin.

The Premium. (See Peerless.)

Truitt Premium (Truitt Improved).—Plant large, limbs long and spreading, prolific; bolls very large, roundish, maturing late; lint 30 to 32 per cent., staple 22 to 25 mm. Very similar to Duncan Mammoth and Mammoth Prolific.

Vick 100 Seed. (See Sugar Loaf.)

Welborn Pet.—Plant erect, slender, limbs short and numerous, very prolific; bolls round, medium in size, clustered, maturing early; lint 31 to 32 per cent., staple 22 to 25 mm. One of the

best known cluster varieties, as it has but little foliage in proportion to the size of the plant.

Williams.—An old short-stapled variety, yielding 33 to 35 per cent. of lint, and probably identical with Peterkin.

Williamson.—Plant not large, limbs short, prolific; bolls small, round, maturing early; lint 30 to 31 per cent., staple 22 to 25 mm.

Willimantic.—Similar to Duncan Mammoth.

Willis.—Similar to Allen; lint 20 to 30 per cent., staple 33 to 37 mm.

Wimberly.—Similar to Duncan.

Wise. (See Peterkin.)

Wonderful (Jones Wonderful).—Similar to Jones Long Staple, but has larger boll and a smaller seed; excellent type of upland long-staple varieties; lint 28 to 30 per cent., staple 35 to 40 mm.

Zellner.—Plant small to medium, limbs short, prolific; bolls medium or small, round, maturing early; lint 30 to 31 per cent., staple 20 to 25 mm.

In the report on cotton of the *Tenth Census*, 58 varietal names were mentioned; but only 6 of the varieties popular in 1880 are still in common cultivation, and these which have stood the test of time are: *Boyd Prolific, Dickson, Herlong, Peeler, Petit Gulf,* and *Texas Storm Proof.*

It has been found, as a rule, that as the percentage of lint is increased the length of staple decreases. The long-limbed varieties grow slowly, require less readily available plant-food and less frequent cultivation than the short-limbed, the latter being a direct product of high culture. It is also found that short-limbed and cluster varieties cannot be made to produce as long a fibre as the long-limbed varieties. As to the relative prices of the lint from the different varieties, this varies greatly from year to year; in 1887 the lint from the long-staple sorts (35 mm. or more) sold in the New Orleans market for nearly double the prices paid for the short staples (20 to 30 mm.).

CLASSIFICATION ACCORDING TO LENGTH OF STAPLE.

Less than 25 mm.	From 25 to 30 mm.	Above 30 mm.
Barnett	Bates Big Boll	Allen
Ben Smith	Bates Favorite	Bailey
Boyd Prolific	Big Boll	Bragg
Brannon	Champion Cluster	Cobweb
Catawba	Excelsior	Colthorp Pride
Chambers	Kieth	Cook
Cherry Cluster	King	Eureka
Dickson	Magruder Marvel	Ferrell
Drake Cluster	Magruder XL	Griffin
Ellsworth	Mammoth Prolific	Jones Long Staple
Grayson	Marston	Matthews
Hawkins	Mattis	Maxey
Herlong	Okra	Moon
Hunnicutt	Ozier	Six Oaks
Jenkins	Peeler	Southern Hope
Jones Improved	Peerless	Willis
Jones No. 1	Roe Early	Wonderful
Minter		
Oats		
Peterkin		
Petit Gulf		
Rio Grande		
Texas Storm Proof		
Truitt Premium		
Welborn Pet		
Williamson		
Zellner		

CLASSIFICATION ACCORDING TO TIME OF MATURITY.

Early.	Medium.	Late.
Bailey	Barnett	Allen
Brooks Improved	Bates Big Boll	Barnes
Cherry Cluster	Ben Smith	Bates Favorite
Dickson	Boyd Prolific	Bragg Long Staple
Drake Cluster	Brannon	Catawba
Early Carolina	East	Champion Cluster
Grayson Early Prolific	Eureka	Cobweb
Hunnicutt	Griffin	Colthorp Pride
Jenkins	Hawkins	Cook
Kieth	Herlong	Ellsworth
King	Jones Long Staple	Ethridge
Matthews	Magruder Marvel	Jones Improved
Oats	Mattis	Mammoth Prolific
Okra	Moon	Marston
Ozier	Peterkin	Minter
Peerless	Peterkin Cluster	Peeler
Pitman	Petit Gulf	Southern Hope
Welborn Pet	Pollock	Texas Storm Proof
Williamson	Six Oaks	Truitt Premium
Zellner		Willis

CLASSIFICATION OF VARIETIES ACCORDING TO LINT.

Less than 30 Per Cent.	From 30 to 34 Per Cent.	More than 34 Per Cent.
Allen	Barnett	Bates Big Boll
Bailey	Bates Favorite	Big Boll
Bragg	Ben Smith	Brannon
Cobweb	Boyd Prolific	Catawba
Colthorp Pride	Chambers	Excelsior
Cook	Champion Cluster	Grayson
Eureka	Cherry Cluster	Jenkins
Ferrell	Dickson	Peterkin
Griffin	Drake Cluster	Rio Grande
Jones Long Staple	Ellsworth	Texas Storm Proof
Matthews	Hawkins	
Roe Early	Herlong	
Six Oaks	Hunnicutt	
Wonderful	Jones Improved	
Willis	Jones No. 1	
	Kieth	
	King	
	Magruder Marvel	
	Magruder XL	
	Mammoth Prolific	
	Marston	
	Mattis	
	Maxey	
	Minter	
	Moon	
	Oats	
	Okra	
	Ozier	
	Peeler	
	Peerless	
	Petit Gulf	
	Southern Hope	
	Truitt Prem um	
	Welborn Pet	
	Wil iamson	
	Zellner	

APPENDIX IV.

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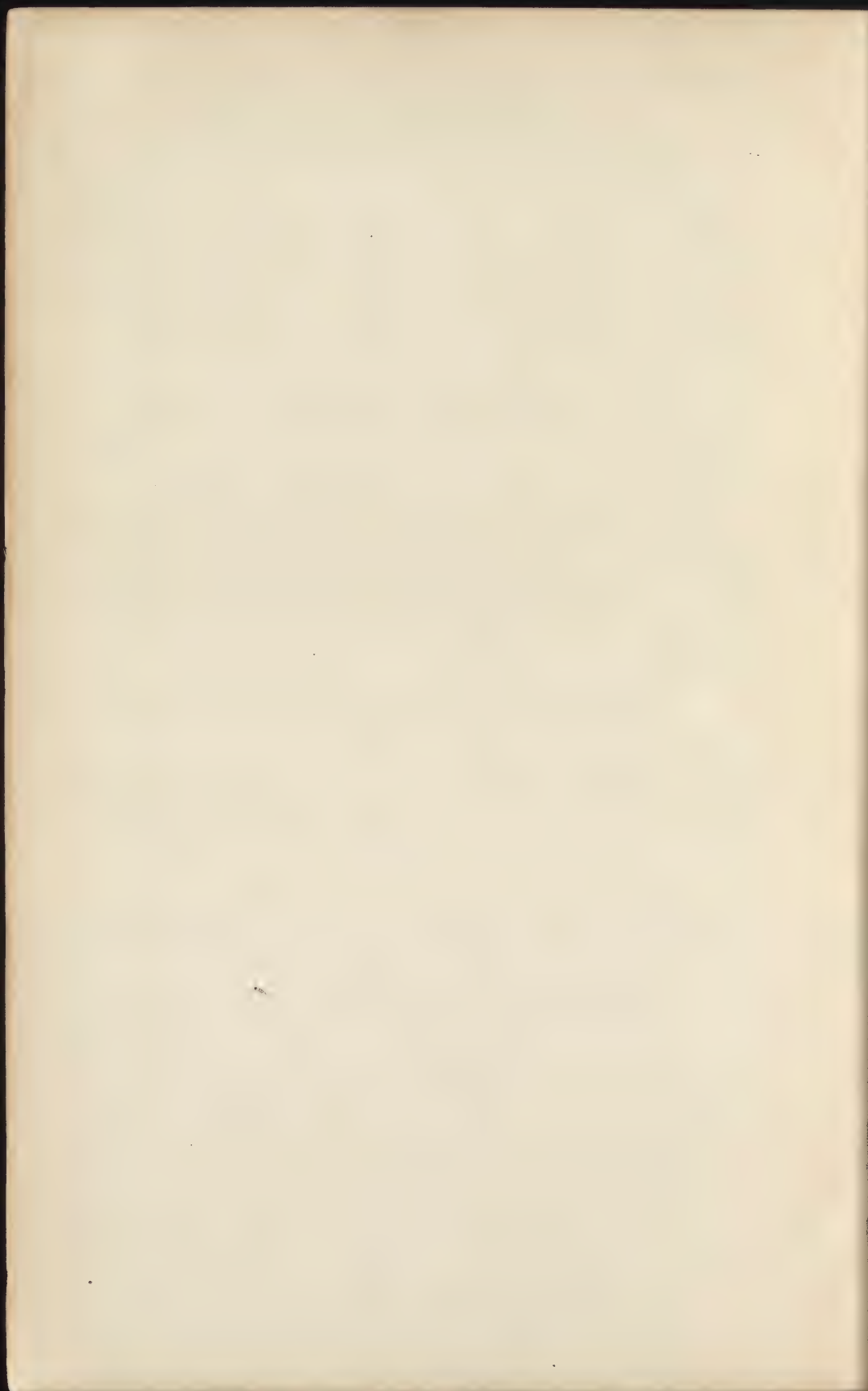Winslow's Systematic Relationship of the Coccaceæ..........Large 12mo, 2 50
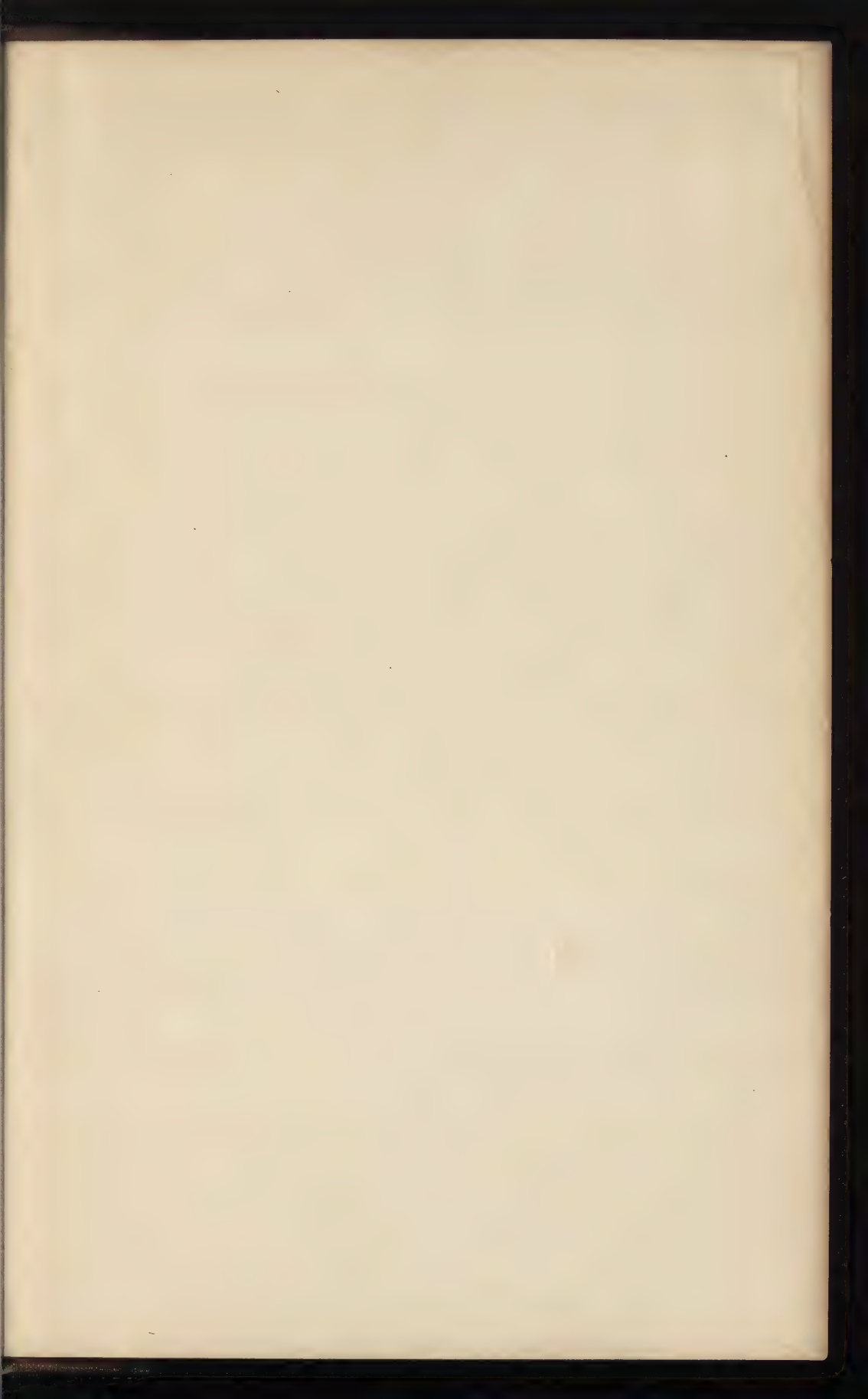
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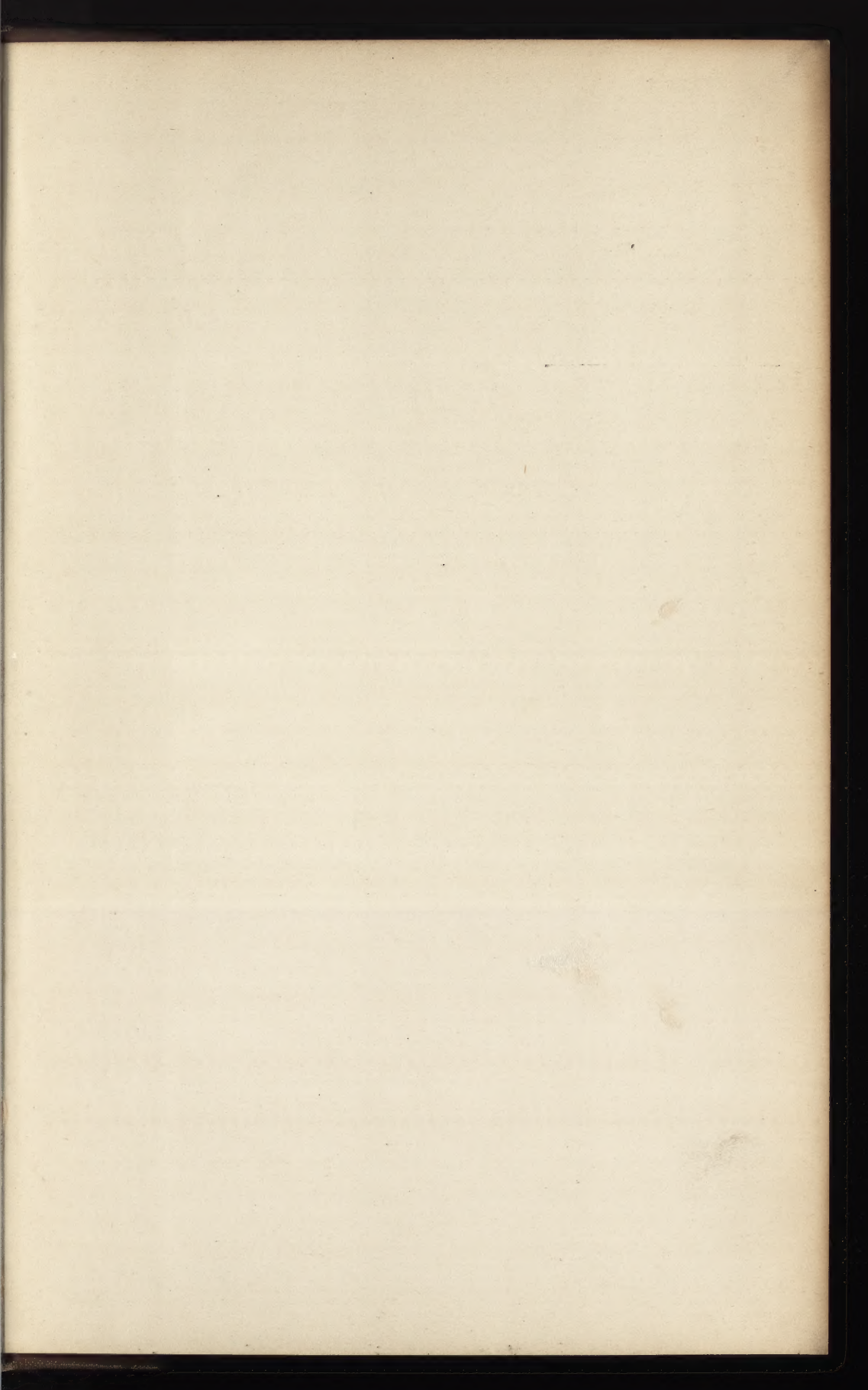Winslow's Elements of Applied Microscopy........................12mo, 1 50

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